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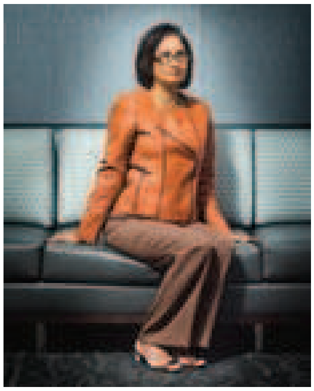

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MARK OSTOW

Technology and Optimism

WHY TECHNOLOGISTS ARE SO CONFIDENT.

In "A Zero-Emissions City in the Desert" *(p. 56)*, Kevin Bullis, *Technology Review*'s energy editor, writes of a nearly empty, dusty building site in the Persian Gulf: "[It] is the start of a vast experiment, an attempt to create the world's first car-free, zero-carbon-dioxide-emissions, zero-waste city. Due to be completed in 2016, the city is the centerpiece of the Masdar Initiative, a $15 billion investment by the government of Abu Dhabi ... . The new development, being built on the outskirts of Abu Dhabi city, will run almost entirely on energy from the sun and will use just 20 percent as much power as a conventional city of similar size."

Nothing like Masdar City has ever been attempted. Although zero-emissions residences and commercial buildings already exist, larger clean buildings have never worked very well. Oberlin College's Lewis Center already has some of the features that Masdar City's designers wish to deploy on a grander scale; but the center consumed far more energy than its architects had anticipated, and only the addition of a solar array in a nearby parking lot allowed the college to claim, dubiously, that the building itself produced as much power as it used. Certainly, no one has ever raised a small *city* to these standards.

Insofar as many environmental engineers doubt that something as complex as a city could ever be entirely green, Masdar City is a triumph of optimism. But if the optimists are right, such a massive demonstration may be necessary. As the chief executive of a sustainable-design company puts it, "People say, 'Gee, that would be great ... but obviously it's not possible.' Once you can point at something, it takes away a lot of those arguments."

Elsewhere in this issue of *Technology Review,* we unveil the 10 emerging technologies that we think have greatest potential to change our world. Among them is a nanofluidic chip that could lower the cost of sequencing DNA so that the entire human genome could be read in eight hours for less than $100. Lauren Gravitz explains, "Despite many experts' doubt that whole-genome sequencing could be done for $1,000, let alone a 10th that much, BioNanomatrix [the startup that invented the chip] believes it can reach the $100 target in five years" *(see "$100 Genome," p. 41)*. That would be a tremendous thing. A cheap, rapid sequencing tool could make personalized medicine a practical reality: a doctor could biopsy a malignant tumor in a patient's lung, sequence its DNA, and then use the genetic information to design the treatment best suited for that particular variant of the cancer—"all for less than the cost of a chest x-ray."

In another story *("But Who's Counting?" p. 64)*, I describe how the absence of common tools for measuring the size of online audiences is threatening the future health of media, as print and broadcast television and radio shrink in importance: "No one really knows how many people visit websites. No established third-party supplier of audience measurement data is trusted. Internal Web logs exaggerate audiences." This matters. Because the content on most websites is free, the only thing that will pay for anything like good journalism is the "display" or banner ads that publishers sell; but the inability to agree on audience numbers is stunting the growth of display advertising. As Roger McNamee, an investor in Forbes, puts it: "Getting this right is absolutely necessary for publishers to be able to continue to do interesting things." No less an expert than McNamee himself confesses that "the remedy is not yet obvious." Yet the story provides a reason for cautious optimism: an innovative San Francisco startup named Quantcast is working on new ways to more accurately measure online audiences.

All three stories point to a similar moral. Faced with large, pressing, global problems—how does one build a green city? Can medicine really be personalized? How can one save publishing?—conservative worthies fret that there may be no immediate solution. But the most innovative technologists are blithely optimistic about their inventions. They are sure that some application of existing or emerging technologies will force a breakthrough on big problems. They are not wholly irrational; they are not like those magical thinkers who proclaim that nothing is impossible if one only wants it sufficiently. But technologists *do* think they understand the difficulties that interest them, and they are happily confident that their particular combinations of technologies will be equal to the challenge.

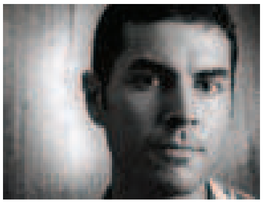
Of course, their confidence may be misplaced. The great anxiety of editing *Technology Review*—and also its great fun—is that while we also understand the day's big problems, we are never entirely certain at the time of publication, even with the best analysis and all our sources, that we have in fact chosen the solutions that will later make the conservative fretters sit up, eyebrows flying, and say, "Well, I'll be *damned*." But we're optimistic that the technologies in this issue will be the ones that matter.

Write to me and tell me what you think at jason.pontin@technologyreview.com. —*Jason Pontin*

LAUREN GRAVITZ reports, for our annual feature selecting 10 important emerging technologies, on a technique for rapidly isolating long pieces of DNA very inexpensively—a boon to the nascent field of personalized medicine *("$100 Genome," p. 41)*. "I thought I had some idea of how cool this technology is, but I had no idea how powerful until I saw it in action," says Gravitz. "Over the course of 15 minutes, they took a sample of commercial DNA, broke it up into long fragments, labeled it, loaded it into one of their chips, and placed the chip on a normal microscope with a camera attached. Suddenly, on the monitor attached to the camera, strands of DNA started flying through the chip, and I realized it was the first time I had ever actually seen molecules of DNA. They were no longer just images in a book." Gravitz also wrote this issue's Demo *("Laser Show in the Surgical Suite," p.88)*, on a laser technique that can prompt wounds to stitch themselves closed. "It was pretty incredible to watch. With just a laser and a bit of dye, the skin appeared to be healing itself," she says. Gravitz is a freelance science writer whose work has appeared in *Discover*, the *Christian Science Monitor*, the *Economist*, and *O, The Oprah Magazine*, among other publications.

GINO SEGRÈ's essay on becoming indoctrinated into the "family" of physics traces in fascinating detail the intertwined ties of famed physicists *("The Family Business," p. 70)*. "In physics, the concept of family can be explored on so many different levels: personal, professional, and institutional," Segrè observes. "My brother, nephew, uncle, father-in-law, brother-in-law, and many cousins all are or were physicists," he says. "Physics has also provided a kind of family feeling to me and others working in the profession, complete with rifts, feuds, and accusations, as well as the more traditional expressions of warmth, trust, and support. I wonder how this family atmosphere has evolved over the past century, as physics has gone from a profession practiced by perhaps a few hundred people, mostly in Northern Europe, to a global enterprise pursued by tens of thousands." Segrè is a professor emeritus of physics at the University of Pennsylvania and the author of *Faust in Copenhagen: A Struggle for the Soul of Physics* and *A Matter of Degrees: What Temperature Reveals about the Past and Future of Our Species, Planet, and Universe*. He is currently working on a new book, but its topic is "a family secret."

MATTHEW L. WALD reports on a development that might help revitalize the nuclear-power industry *("Traveling-Wave Reactor," p. 42)*. The traveling-wave reactor could allow a small bit of fuel to power a plant for hundreds of years without the need to refuel. "The underlying idea is analogous to cooking a Thanksgiving turkey breast-side down," says Wald. "Sometimes using the standard ingredients but in a different way can produce a better result. In this case, the raw ingredient is still likely to be uranium, but if this reactor runs as advertised, it would make much of its fuel as it operated, cutting the cost of preparing fuel and stretching uranium supplies." Wald is a reporter for the *New York Times*, where he has written about nuclear power since 1979.



OLIVIER ASSELIN shot the photographs for a TR10 story about a way to store Web pages that is cheaper and uses less energy than current methods *("HashCache," p. 52)*. The advance could provide faster access to Web content in countries with limited bandwidth. "Technology is quickly changing things in Africa," he says. A Canadian photographer based in Ghana, Asselin has had work in *Time*, *Newsweek*, the *New York Times*, and other periodicals.

ON THE GRID

David Talbot's article on the power grid ("Lifeline for Renewable Power," January/February 2009) tells of the discontinuity between the present utility system and any future system that might depend on renewable sources of energy. The problem is that utilities are built to serve people where they live, while sun and wind are most plentiful where they don't.

January/February '09

May I offer an idea? In the 19th century, the United States managed to construct a vast and reliable rail system when the government granted huge concessions in real estate to railroad companies, which then proceeded to develop the miles of land on either side of the tracks they built. Today, the government owns vast tracts of inhospitable land, so why not do something similar to get energy grids out into those empty, windy, sunny regions? Give concessions to utilities to build nuclear plants, on the provision that they build large grids to collect power from the renewable sources that obtain there. The virtue of this idea is that it will be up to private markets to raise the funds and up to private companies to construct the hardware—usually a pretty efficient way to go.

Charles A. Berg
Former chief engineer
United States Federal Power Commission
Buckfield, ME

David Talbot's wide-ranging review of improvements needed for a better power grid was flawed by its failure to recognize the role of nuclear power, which is effectively dismissed as nonrenewable. Obviously, we can't require each and every power source to be indefinitely renewable—just clean, safe, cost-effective, and sustainable for a reasonable time. Safety concerns about nuclear power plants are often overstated, and waste issues are solvable with a combination of repository design, maintenance, and replacement planning. *TR* can play a role in educating nontechnical people about these issues, rather than assuming that nuclear power has no role to play in energy independence or atmospheric-carbon control. By making this assumption, the article nibbles around the edges of the energy problem instead of contributing to a complete solution.

David Korenstein
Wayne, PA

Cathy Zoi's notebook on clean energy ("Rebuilding the Power Grid," January/February 2009) is unscientific. The economy is not "collapsing"; it is contracting. The bursting of a credit bubble caused this, not an "addiction to fossil fuels." Generating 100 percent of our electricity from carbon-free sources within 10 years is not an "achievable goal"; it is a scientifically and economically unsupportable fantasy. We surely have many real challenges to face that could be overcome with technology. Publishing hysterical political propaganda is not helpful. I have been faithfully reading *TR* since I graduated from MIT in 1976. I applauded when John Benditt rescued and rebuilt the magazine, which had fallen into the hands of left-wing ideologues. I hate to see the magazine's editorial policy backslide.

William Frezza
Charlestown, MA

Editor David Rotman responds:
Mr. Frezza is welcome to his opinion on whether the economy is collapsing or merely contracting, and whether generating carbon-free electricity is actually achievable. But I must point out that *Technology Review*'s editorial policy is now, as it was when John Benditt redesigned the magazine in the spring of 1998, to present clear and precise explanations of promising technologies, and to present differing opinions on the future of these technologies.

AN APPRECIATION

I want to thank Mark Williams for his moving tribute to my husband, Algis "Ajay" Budrys ("The Alien Novelist," November/December 2008). It was so encompassing of his entire life and brought tears to my eyes as I read it. I hadn't realized that Ajay's interview with *Technology Review* was so close to the end and am impressed with how true to him it was. It made me feel as if I were listening to him again as he recalled stories of his youth that I had heard over the 54 years we were together.

Edna Budrys
Chicago, IL

ZERO GRAVITY?

The caption on page 60 of *TR*'s oral history of space tourism ("'Very Stunning, Very Space, and Very Cool,'" January/February 2009) reads, "Charles Simonyi experiences zero gravity aboard a Russian aircraft." No airplane flies in zero gravity. People become weightless because the airplane flies a path that does not support them; when they are weightless they are really in free fall, accelerating toward Earth as a result of gravity!

James F. Jackson
Carlisle, IN

Correction: On pages 34–35 of the January/February 2009 issue, we misattributed credit for photographs of the Am386 and Motorola 68000 chips. They were photographed by William Blair.

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NOTEBOOKS

Expert opinion

MEDICINE

Global Health

MEDICAL TESTS FOR POOR COUNTRIES NEED TO BE PROPERLY FIELD-TESTED, SAYS JOSÉ MIGUEL TREVEJO.

Applying modern diagnostic technologies to disease management around the globe could dramatically improve patient care. Unfortunately, many such technologies are not available or not usable in resource-poor settings.

In sub-Saharan Africa, for example, health-care practitioners treating children with severe fevers have to either make an educated guess or use a "shotgun" approach, treating for all potential illnesses from malarial infection to bacterial pneumonia. The inability to arrive at a specific diagnosis not only delays proper therapy but can increase death rates. A recent study has shown that mortality is almost twice as high in patients mistakenly diagnosed as having malaria. Those deaths could be dramatically reduced with a reliable test that can be given at the bedside.

With current advances in low-cost, portable technologies *(see "Paper Diagnostic Tests," p. 44)* and increasing knowledge of the biology of disease, the time is ripe to bring novel diagnostic tools to those who desperately need them. Accurate diagnoses will not only help individual patients but also yield more-precise measurements for public-health and treatment programs.

It is imperative, however, that new diagnostics be developed and tested as early as possible in the settings where they will be used—preferably in collaboration with local researchers and clinicians. Hospitals in the developing world are littered with broken x-ray machines and other donated medical equipment that does not work in humid conditions and has no replacement parts. Most businesses wouldn't think of releasing a new product without sufficient market research or testing, and the same should be true for field-testing medical devices. Such testing will help avoid two problems that have hobbled earlier efforts: pushing newer technologies when existing or simpler technologies would be as effective, and attempting to apply technologies that work well in the controlled, sterile environment of the laboratory but not in the real world.

Given that different diseases are endemic to specific parts of the world, and that regions differ in genetics, environment, culture, sociopolitical infrastructure, and the biology of particular pathogens, a "one size fits all" approach to diagnostics is rarely appropriate. The steps leading from a promising diagnostic technology to a robust working product must be thoughtfully executed to ensure that the enormous potential of these tests is fulfilled in the places where they can do the most good. TR

JOSÉ MIGUEL TREVEJO IS A PRINCIPAL SCIENTIST AT CHARLES STARK DRAPER LABORATORY.

COMPUTING

Solving AI

PEDRO DOMINGOS EXPLAINS WHY WE NEED A NEW LANGUAGE FOR ARTIFICIAL INTELLIGENCE.

The goal of artificial intelligence (at least according to the field's founders) is to create computers whose intelligence equals or surpasses humans'. Achieving this goal is the famous "AI problem." To some, AI is the manifest destiny of computer science. To others, it's a failure: clearly, the AI problem is nowhere near being solved. Why? For the most part, the answer is simple: no one is really trying to solve it. This may come as a surprise to people outside the field. What have all those AI researchers

been doing all these years? The reality is that they have largely given up on the grand ambitions of AI and are instead working on increasingly specialized subproblems: not just machine learning or natural-language understanding, say, but issues within those areas, like classifying objects or parsing sentences.

I think that this "divide and conquer" approach won't work. In AI, the best solution to a problem viewed in isolation often gets in the way of solving the larger problem. To make real progress, we need to work on "end to end" problems—self-contained tasks, like read-

BOB LONDON

ing text and answering questions, that entail a number of subtasks *(see "Intelligent Software Assistant," p. 48)*. Until now, it hasn't really been possible to do this, because the necessary computing power was not available. But within a decade or so, computers will surpass the computing power of the human brain. (While computers are extremely efficient at specific tasks, such as arithmetic, human brains are still ahead in terms of the number of operations they can perform per second. When this is applied to things that people are good at, like vision and language understanding, computers lose.)

Computing power is not the whole answer, though. Previous attempts to solve end-to-end AI problems have failed in one of two ways. Some oversimplified the problems to the point that the solutions did not transfer to the real world. Others ran into a wall of engineering complexity: too many things to put together, too many interactions between them, too many bugs.

To do better, we need a new mathematical language for artificial intelligence. Examples from other fields of science and technology demonstrate just how powerful this can be: mechanics, for example, benefited from calculus; alternating current from complex numbers; and digital circuits from Boolean logic. Today these things seem like second nature to their practitioners, but at the time they were far from obvious. The key is finding the right language in which to formulate and solve problems.

What should be the language of AI? At the least, we need a language that combines logic and probability. Logic can handle the complexity of the real world—large numbers of interacting objects, say, or multiple types of objects—but not its uncertainty. Probabilistic graphical models have emerged as a general language for dealing with uncertainty, but they can't handle real-world complexity.

The last decade has seen real progress in this direction, but these are still early days. It's unlikely that we'll find the language of AI until we have more experience with end-to-end AI problems. But this is how we're ultimately going to solve AI: through the interplay between addressing real problems and inventing a language that makes them simpler. TR

PEDRO DOMINGOS IS AN ASSOCIATE PROFESSOR OF COMPUTER SCIENCE AND ENGINEERING AT THE UNIVERSITY OF WASHINGTON IN SEATTLE.

ENERGY

Green Nuclear

NUCLEAR POWER SHOULD BE PART OF THE RENEWABLE-ENERGY PORTFOLIO, SAYS ANDREW KADAK.

The Obama administration took office amid high hopes that it would come up with a strategy for clean, renewable energy that can work to lessen our dependence on foreign oil and reduce the pollutants associated with fossil fuels. What is puzzling, however, is the notable exclusion of nuclear energy from its portfolio of clean energy sources, which include hydroelectric, wind, and solar power. More than 73 percent of non-carbon-dioxide-emitting energy in the United States is nuclear energy. This power source supplies the country with about 20 percent of its electricity needs, while wind and solar power together supply less than 1 percent.

There is no rational explanation for the exclusion. The ability of the 104 operating U.S. nuclear plants to provide safe, clean energy is no longer in dispute, given their remarkable record since the Three Mile Island accident 30 years ago. Nor do most people question whether nuclear energy produces greenhouse gases. Is nuclear excluded because it is not perceived to be a "renewable" energy source in the way that power from the wind and sun is replenishable? In fact, some existing nuclear technologies are clearly renewable, making more fuel than they consume. These so-called breeder reactors are able to process the waste from existing reactors into fuel for their own use. Such reactors are already operating in Russia, France, and India and will soon be running in China and Japan. (Although this technology has not been deployed in the United States, the first reactor to make electricity in this country was a breeder reactor, called the Experimental Breeder Reactor-I, which began operation in the early 1950s.)

In the next 100 years or so, as our sources of fissile uranium are depleted, breeder reactors could turn existing mined-uranium wastes and high-level nuclear waste from our current fleet of water reactors into a source of clean energy that could last for thousands of years *(see "Traveling-Wave Reactor," p. 42)*.

Nuclear power must be given all the incentives offered to solar and wind energy, including carbon credits and loan guarantees. If we are serious about addressing the problems of energy dependence and global climate change, nuclear must be part of the solution. TR

ANDREW KADAK IS PROFESSOR OF THE PRACTICE IN THE MIT DEPARTMENT OF NUCLEAR SCIENCE AND ENGINEERING.

SPOTLIGHT ON INNOVATION

A TECHNOLOGY REVIEW CUSTOM SERIES

The Technology Review Custom Team takes a look at the technologies that are changing the way we live and do business. The third article of four looks at the advances in personalized medicine and the convergence of genetics and the health-care industry.

MAKING MEDICINE PERSONAL

A number of scientists bared their genetic souls recently as part of the Personal Genome Project, a study at Harvard University Medical School. They were among the first of the eventually 100,000 volunteers who will agree to place their genetic profiles on the Internet.

Genetic profiling can provide information on what diseases may befall us. And knowledge of an individual's genetic makeup may also help scientists figure out how to treat diseases—part of an emerging field known as personalized medicine.

As many doctors freely admit, says Julie Johnson, director of the Center of Phamacogenomics at the University of Florida (UF), prescribing medicine is "more of an art than a science." Approved drugs work—but not 100 percent of the time, and not for 100 percent of the population. Some people have no response to certain drugs, and others experience severe side effects.

What determines whether a particular treatment is effective or leads to severe side effects is our genes, scientists believe. Personalized medicine holds the promise of tailored medical treatments based on genetic information, rather than a one-size-fits-all approach.

The UF center participated in studies on warfarin, a blood thinner prescribed for millions of Americans to prevent heart attack or clotting after a heart attack. Too little of the drug causes a risk of clotting, and too much can cause excessive bleeding. "There's a very narrow window, and there's a great deal of variability among patients," says Johnson. "A lot of work in the past decade has uncovered several genes that help

"We all have friends who can eat french fries every day and never gain weight, while the rest of us will have a hard time getting the belt to fit."

explain a great deal of that variability." In 2007, the FDA cleared a genetic test for sensitivity to warfarin to help doctors prescribe the correct dosage, although the tests are not yet widely implemented.

The UF center is also focusing research on drugs prescribed for hypertension, in an attempt to find the genes that "will predict how much a person's blood pressure will go down if they're administered certain medicines," says Johnson.

SPEEDING THE PROCESS

Part of what has contributed to the increasing interest in personalized medicine is the speed and cost of sequencing genomes. The first human genome took many years and millions of dollars to sequence. The price has already dropped into the thousands instead of millions of dollars, and it's expected to continue to fall. The journal *Science* listed "faster, cheaper genome sequencing" as one of the top scientific advances in 2008.

These advances have increased the speed of research in the field. John Reed, the president and CEO of Burnham Institute for Medical Research, a center with campuses in California and Florida, says that the Florida campus has engaged in major initiatives related to personalized medicine. While Burnham's research has traditionally focused on cancer and on neurodegenerative and inflammatory diseases, the scientific team is expanding into obesity, diabetes, and metabolism research.

"We all have friends who can eat french fries every day and never gain weight, while the rest of us will have a hard time getting the belt to fit," says Reed. "There are genetic differences in how we metabolize food—individual metabolic rates, hormone signaling—that's all just being worked out." Burnham is partnering with the clinical research institute at Florida Hospital, particularly the diabetes center, to engage in research on the metabolic systems of the patients there.

The fields of genome research and rapid drug discovery are coming together to enhance each other, says Reed, "we'll be able to, with far more accuracy, define for whom a drug is really going to work, and to avoid a lot of trial and error that we experience when we're confronted with a health issue." He and other researchers in the field see a time not too far in the future when understanding individual genomes will lead to better, more effective medical treatments for everyone.

Continues online:
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DIAGNOSTICS

TB DRUG COMPLIANCE

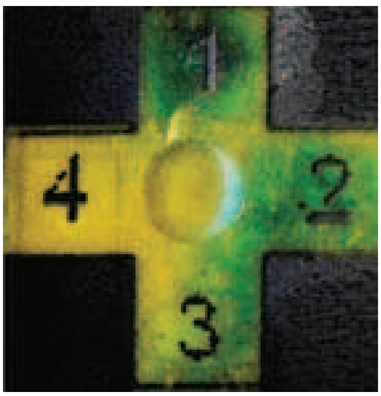
Paper drug tests and text messaging could help thwart the most deadly strains of tuberculosis

TAKE YOUR MEDS
Paper tests reveal hidden codes (bottom) when exposed to the urine of patients who have taken tuberculosis medication. The codes can be numerical sequences or bar codes (top).

DRUG-RESISTANT tuberculosis is a major public-health problem in poor nations. While antibiotics can effectively treat TB, they cause nausea and other side effects, and many patients stop taking them a month or two into the six-month treatment regimen. That can foster drug-resistant forms of the infection, which are deadlier and more expensive to treat.

A new monitoring system that combines cheap, paper-based diagnostics with text-messaging technology could help health organizations, with the coöperation of telecommunications companies, give patients another incentive to adhere to the drug regimen. José Gómez-Márquez, program director for the Innovations in International Health program at MIT, and his collaborators developed a simple paper-based test that detects metabolites of the TB drug in urine. The metabolite reacts with chemicals in the paper, revealing a simple numerical code. A patient would take the test daily and text the code to a central database. Those who take the drugs consistently for 30 days would be rewarded with cell-phone minutes.

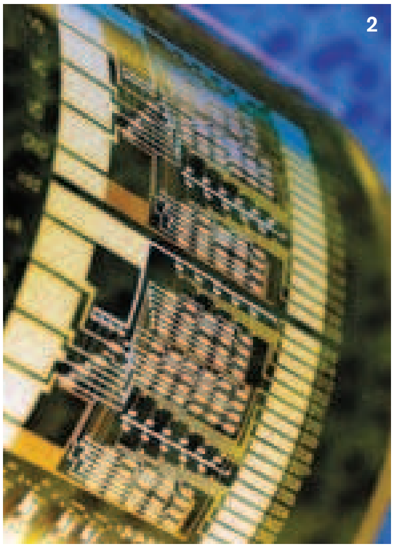
In a pilot study in Nicaragua, the researchers worked with local scientists to ensure the accuracy of the test strips,



CHRISTOPHER HARTING; INSET: JOSÉ GÓMEZ-MÁRQUEZ

testing them on urine samples collected from TB patients. They also determined that the strips could be stored reliably and that they worked as well in humid Nicaragua as they did in New England.

The team is developing a device that dispenses the paper tests in the proper order, so that the sequence of the codes will correspond to that stored in the database. A larger trial recently began in Karachi, Pakistan. —*Emily Singer*



1. STRETCHY SPEAKERS
A transparent, stretchable film of carbon nanotubes made by Shoushan Fan at Tsinghua University in China can act as a loudspeaker even when mounted on a waving flag. Overlaid on a computer monitor, the film could eliminate the need for separate speakers. Current running through the nanotubes heats the film, creating sound waves in the air through the thermoacoustic effect.

2. PRINTABLE INTEGRATED CIRCUITS
Circuits deposited with printing techniques are cheap to make, but the semiconducting "inks" they use tend to limit their performance. Inks using carbon nanotubes could change that. Printed nanotube circuits made by John Rogers at the University of Illinois at Urbana-Champaign are not only fast but flexible.

3. CONDUCTIVE CLOTHES
By dip-coating cotton threads in carbon nanotubes, Nicholas Kotov at the University of Michigan turns them into "wires" for wearable electronics. The threads can be woven into fabrics and carry enough current to power an LED *(shown here)*. Attaching antibodies to the nanotubes converts the fabrics into biosensors that could register pathogens or detect bleeding in patients or soldiers on the battlefield.

4. TRANSPARENT ELECTRODES
In a typical flat-panel display, liquid crystals are sandwiched between electrodes, which must be transparent so that light can pass through them. Unidym, a company in Menlo Park, CA, uses a roll-to-roll printing technique to rapidly coat plastic with carbon nanotubes. The resulting films could replace the brittle, expensive indium tin oxide electrodes used in most displays. Unidym plans to begin selling the films later this year. With Samsung, the company has made prototype e-paper readers. It's also working on color LCDs and thin-film solar cells.

JOHN ROGERS (2); AMERICAN CHEMICAL SOCIETY (1, 3); UNIDYM (4)

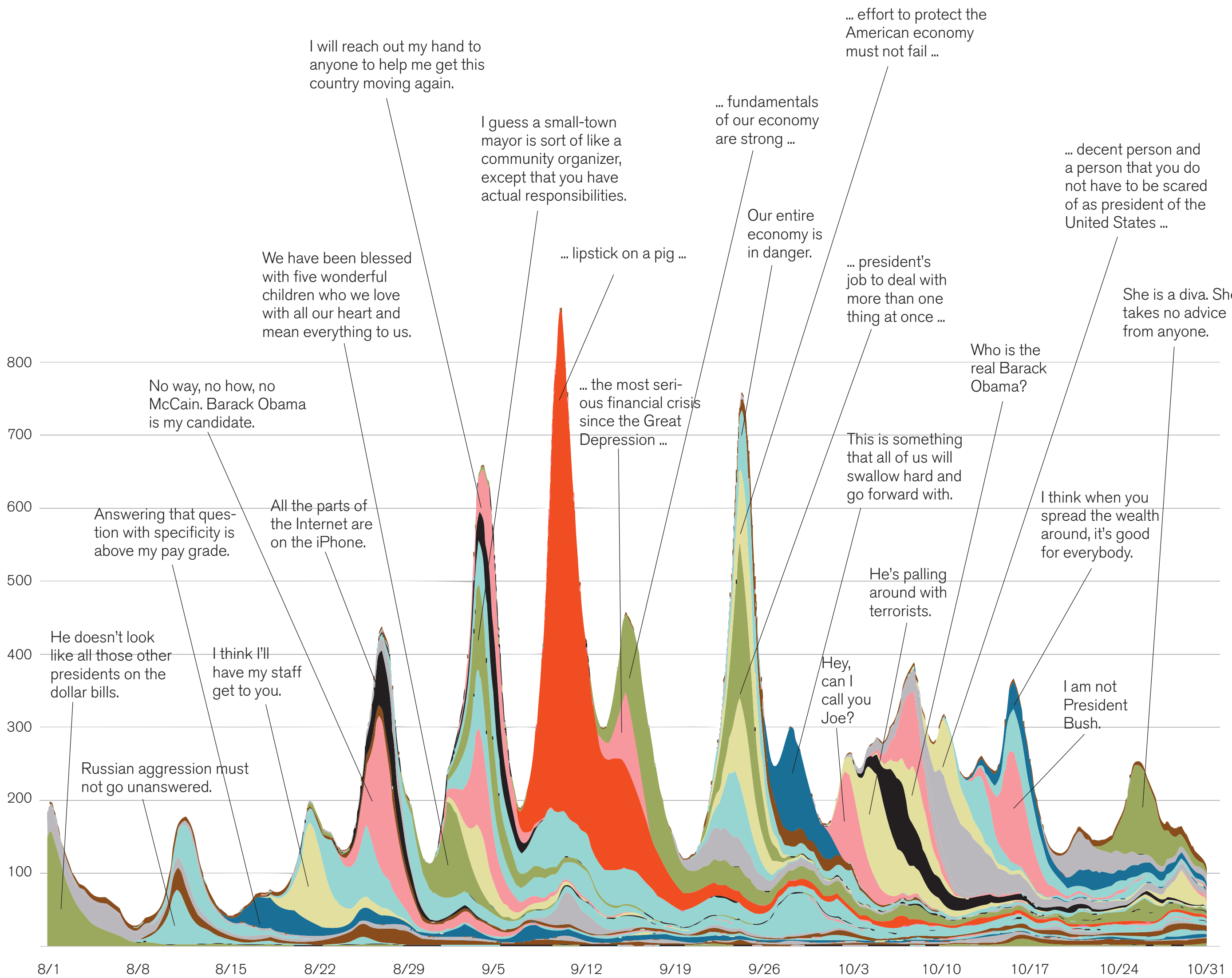
MATERIALS

NANOTUBE ELECTRONICS

Prototypes bring practical nanotube devices closer

CIRCUITS MADE from carbon nanotubes are intrinsically faster than those made from silicon. But while products from tennis rackets to bike frames take advantage of nanotubes' light weight and strength, no commercial devices have yet exploited their remarkable electrical properties.

That's partly because researchers have had difficulty creating films or other assemblies of nanotubes that preserve those properties: nanotube arrays, for example, proved nowhere near as electrically conductive as tubes taken singly. But a number of groups have found ways around that obstacle, and the result has been a flurry of prototype electronic devices that use nanotubes. Here is a sampling. *—Katherine Bourzac*



DATA MINING

BUZZ METER

Data mining sheds light on what makes news

JURE LESKOVEC, LARS BACKSTROM, AND JON KLEINBERG

POLITICAL SCIENTISTS have long studied the news cycle, tracking which people and topics drive coverage and for how long. But the sheer volume of news outlets made it hard to quantify their results.

Researchers at Cornell University are trying to get a quantitative handle on how news stories proliferate. Computer scientist Jon Kleinberg reasoned that instead of trying to sort items from blogs and news sites into arbitrary categories, he could home in on quotes to identify their topics computationally. But references to a quote might extract different phrases from it, change its tense, or paraphrase it, resulting in dozens of different versions. So Kleinberg and his colleagues developed algorithms that determine family resemblances between strings of words in different articles.

The researchers are now canvassing about a million online news items a day. Focusing on quotes might exclude some relevant items, but it helps identify the types of stories that prove most popular and the websites that report on them first. The researchers have found that with the exception of a handful of professional political blogs that are the fastest to sniff out a story, mainstream media sites drive coverage, converging on a story two and a half hours before blogs react. But mainstream sites are also quick to abandon stories, while blog interest can persist for days. –*Matt Mahoney*

POP CHART This graph depicts the 50 phrases that generated the most buzz online in the last three months of the 2008 presidential campaign. The vertical axis indicates the number of Web items featuring some version of the phrase posted hourly; the horizontal axis shows fluctuation over time. Each phrase has an associated color, some labeled with phrase excerpts.

<THINK CITY
Think says that 1,600 of its small, all-electric commuter cars are already on the road, but the company barely staved off bankruptcy in late 2008.

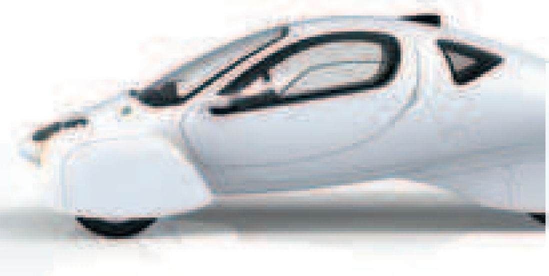
CHEVY VOLT>
GM's plug-in hybrid, due in late 2010, will have an electric-only range of 40 miles—enough for most daily commutes.

BMW MINI E>
The first battery-powered Minis should debut in March. But BMW is leasing only 480 of the vehicles in a pilot study, at $850 a month.

SMART FORTWO>
By late 2010, Daimler plans to release about 400 electric versions of its Smart commuter car in several pilot programs worldwide.

<PLUG-IN PRIUS
Like BMW with the Mini, Toyota will ship 500 plug-in versions of its 2010 Prius this year. The car's electric-only range should be 10 miles.

BYD F3DM>
The Chinese company BYD released its plug-in hybrid in China at the end of 2008 and says that it could reach the U.S. by 2010.



<APTERA 2E
Aptera plans to begin production of its small, three-wheeled car this fall and says that it has orders from 4,000 customers.

AUTOMOTIVE

ELECTRIC AVENUE

Amid a welter of high-profile announcements, electric vehicles and plug-in hybrids will remain rare sights

THE TALK at this year's Detroit Auto Show was all about electric cars and plug-in hybrids—hybrid cars whose batteries can be recharged from wall sockets. But both types of vehicles will remain uncommon on U.S. highways for several years. Although both Ford and Chrysler have said that they will release electric vehicles in 2010, they had disclosed no further details at press time. Several companies expect to beat Chevrolet's ballyhooed Volt plug-in to market but are limiting production runs and plan to gather data on how their vehicles are used before broader commercial releases. Other companies are concentrating on small, sometimes eccentric-looking vehicles for city commuting, but it's still unclear whether drivers will embrace the idea. *—Larry Hardesty*

DAVID DEWHURST (PRIUS); ALL OTHERS COURTESY OF MANUFACTURERS

CRYPTOGRAPHY

THE CAPTCHA ARMS RACE

Researchers mull the next step in spam deterrents

SPAMMERS USE automated programs called bots to harvest online data, so in 2000, a group of researchers created a bot deterrent called the Captcha—the "completely automated public Turing test to tell computers and humans apart." The first Captchas required people to type in words displayed as images on a Web page in order to access a website.

But as bots have gotten smarter and Captchas more complicated, two problems have arisen. The first is that the Captchas can be hard for humans to solve, too. The second is that spammers have simply enlisted networks of humans to attack Captchas.

Researchers are tackling both problems. For instance, Jon Bentley of Avaya Labs and Henry Baird, a professor at Lehigh University, have proposed "implicit Captchas" that would present a number of small tests as part of the natural experience of browsing a website. To move from one page to the next, the user might have to click a particular object in an image. Though relatively simple, the tests would be numerous enough to establish that it's probably a human at the keyboard. But navigating a site would require so much human attention that it wouldn't be cost effective for spammers to hire networks of Captcha breakers.

Until such new techniques prove themselves in the real world, though, Luis von Ahn, a Carnegie Mellon professor who helped develop Captchas, thinks Web surfers have no choice but to muddle through even difficult ones. "If you got rid of them, all hell would break loose," he says. —*Erica Naone*

MUTATIONS Captchas initially featured familiar words and typefaces but soon evolved into gibberish with distorted backgrounds. Then the words themselves began to warp and in some cases gave way to pictures.

STARTUPS

NETWORKING STAYS CONNECTED

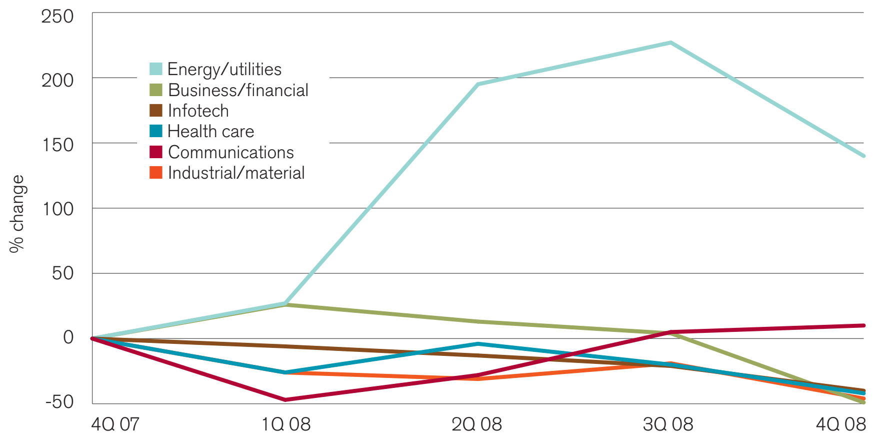
Communications companies buck the fourth-quarter slide

IN THE FOURTH quarter of 2008, venture investment in the United States plummeted by more than 25 percent. Even energy and utility companies, which saw enormous growth in investment in 2008, suffered their first quarterly drop-off of the year.

But one subsector of the information technology industry, which VentureWire calls communications and networking, enjoyed an unexpected surge. Indeed, it was the only sector to see an increase in funding over both the previous quarter and the fourth quarter of 2007.

Much of that jump was due to two startups that received $100 million each. One of them, Pocket Communications, offers a contractless, flat-rate, unlimited-calling cell-phone plan. The other, Open Range, plans to bring wireless broadband to rural areas but is not yet disclosing any details about its technology. But a number of other companies with innovative technologies also received significant funding.

HARD WINTER | Quarterly funding relative to Q4 '07



Source: VentureWire

PUREWAVE

PureWave's wireless broadband transceiver uses multiple antennas to increase its data capacity sixfold. Beams from separate antennas cancel each other out only in certain directions, so transmissions can be aimed at particular users. A transmitter—or two transmitters near each other—can thus use the same transmission frequencies for multiple users, without fear of interference. The device uses software to switch between transmission protocols, so it should be compatible with several standards for wireless broadband.

Product: Wireless-broadband base stations
CEO: Gideon Ben-Efraim
Location: Mountain View, CA
Funders: Leapfrog Ventures, ATA Ventures, Allegis Capital, Benhamou Global Ventures
Funding: $20 million
URL: pwnets.com

AWAREPOINT

Awarepoint has a novel twist on the RFID systems that many hospitals use to track equipment. Its tag readers plug into ordinary wall sockets, so there's no need to string new cables throughout the hospital. The readers then organize themselves into a wireless mesh network, monitoring each other's signal strength and calculating the most efficient way to route information. If one reader malfunctions or is obstructed, the others route around it. The readers generate less than a milliwatt of power each, so they don't interfere with hospital equipment, as some systems do.

Product: RFID tracking system for hospitals
CEO: Jason Howe
Location: San Diego, CA
Funders: Cardinal Partners, Avalon Ventures, Venrock
Funding: $19.3 million
URL: awarepoint.com

LUXTERA

Computers, which process data electronically, use silicon circuits; optical networks, which transmit data on beams of light, use lasers and receivers made from more exotic and expensive semiconductors. The ability to make optical components from silicon would lower manufacturing costs and let computers process optical data more quickly. Luxtera was the first company to bring silicon optics to market, with a data cable that went on sale last year. At trade shows, it has begun demonstrating a prototype cable for video systems, likely to be its next product.

Product: Silicon-based optical equipment
CEO: Greg Young
Location: Carlsbad, CA
Funders: Advanced Equities Financial, August Capital, New Enterprise Associates, Sevin Rosen Funds
Funding: $72.9 million
URL: luxtera.com


Technology Review
PUBLISHED BY MIT
I am the future of technology.
MARTIN ZACHARIAS
SENIOR PRODUCT ENGINEER, NISSAN
As a senior product engineer for Nissan, Martin is involved in determining what features or technologies will be available to enhance the customer's driving experience. How does Martin look into the future of technology? "The Technology Review properties give me an insight into what's being developed in other industries," he says. "They are among the valuable resources I use because there are many technologies used in vehicles today that originated or were derived from other industries."
Thomas J. Gustainis
TECHNOLOGY REVIEW READER PROFILE SERIES
www.technologyreview.com/reader

Technology Review's Career Resources

Do you want to take the next step toward professional growth? Career Resources brings you success stories from executives who continued their education, essential advice from experts on how to achieve your career goals, and a directory of programs designed specifically for the working professional. **www.technologyreview.com/careerresources/**.

Career Growth Profile

Humayun Arif

Age: 54

Job Title: Space Initiatives Manager, Global Government Solutions Group

Employer: Cisco Systems, Inc.

Graduate Programs: MBA, Executive Program, Kellogg School of Management, Northwestern University

Humayun Arif has been instrumental in reshaping NASA for the next 30 years of space communication. He has played a key role in positioning Cisco Systems as the recognized industry collaborator in NASA's $104 billion Constellation Program to return humans to the moon and to Mars.

Last January, Arif embarked on yet another challenging mission: earning an executive MBA degree from Northwestern University's Kellogg School of Management. Never mind that he's a recognized expert in his field. Never mind that he's 54 years old and has more than 20 years' experience. Arif says he's in need of some education.

"Over the last few years, it has been readily obvious to me while interacting with Cisco's business units that there is strong interdependence of technical decision-making with business economics. One cannot be performed without the other," says Arif, who is a space initiatives manager for U.S. civil programs with Cisco Systems' Global Government Solutions Group. "The value of an MBA ... has clearly become evident."

Arif also admits that he is pursuing an executive MBA degree because his leadership skills could use some reinforcement—particularly in formulating strategies, solving problems, and making decisions in a team environment.
"And finally, there is the age-related factor of keeping the brain engaged, given the current work scenario of never retiring," he says.

With increasing numbers of working professionals going back to school, universities are responding with flexible MBA programs, such as online and evening formats. An executive MBA program typically holds class every other weekend for two years, plus some weekday getaways for immersion workshops or a business consulting practicum. Arif says he opted for the executive program because it's geared toward professionals who have a minimum of 10 years' experience in their respective industries.

To read more about how Humayun plans to put his MBA to use, visit **www.technologyreview.com/careerresources/**.

Program Directory

JOSHUA SCOTT

SENSORS

180° SURVEILLANCE CAMERA

TO COVER a 180° field of view, most surveillance cameras either swivel on remote-controlled mounts, which means they can miss suspicious activity, or use fish-eye lenses, which can introduce distortions. A new camera stitches images from five inexpensive, fixed sensors—the same kind used in camera phones—into a single, undistorted 180° picture. The Ethernet-connected device is the size of a light switch and transmits video at 15 frames per second, along with a seven-megapixel still image every second or two.

Product: Digital Window D7 Camera **Cost:** $600 to $1,000 **Source:** www.scallopimaging.com
Company: Scallop Imaging

AUDIO

Volume-Limiting Headphones

SOUNDS louder than 85 decibels can cause hearing loss, but most digital music players can exceed that threshold. Headphones and ear buds from iHearSafe of Milford, NH, have a volume-limiting circuit hardwired into the cord. Unlike the software that some concerned parents have used to cap the volume of their kids' music players, the hardwired circuit can't be digitally circumvented.

Product: iHearSafe ear buds, headphones, and ear clips
Cost: $19.99 for ear buds and $24.99 for headphones or ear clips
Source: www.ihearsafe.com
Company: iHearSafe

INTERFACES

3-D WEBCAM

ONLINE VIDEO chat has gone 3-D. A new webcam with two cameras spaced approximately as far apart as human eyes sends two offset images to a computer. In real time, software processes the images according to how they'll be viewed: the camera comes with five sets of blue-red 3-D glasses for use with ordinary monitors, but the software can also output images in the format used by new 3-D displays. The webcam is compatible with such applications as Skype, AOL Instant Messenger, and YouTube.

JOSHUA SCOTT

Product: Minoru 3D Webcam **Cost:** $89.95 **Source:** www.minoru3d.com **Company:** Promotion and Display Technology

CRYPTOGRAPHY

Pill ID

TO DETER the theft and counterfeiting of medication, NanoGuardian has developed a way to apply nanoscale patterns to individual pills and capsules so that they can be authenticated or traced. The company won't say how the technology works but claims that the mechanism for producing the pattern can be built into a capsule mold. Detection of the nano pattern has to be performed by NanoGuardian itself, using proprietary means. The technology has been approved by the U.S. Food and Drug Administration for use by a NanoGuardian client.

Product: NanoCodes **Cost:** A fraction of a penny per pill **Source:** nanoguardian.net **Company:** NanoGuardian

INTERFACES

INTERNET CAR RADIO

INTERNET RADIO lets listeners find or create stations that play just the music they like. A dashboard stereo from miRoamer and Blaupunkt brings that kind of control into the car. The stereo connects wirelessly, via Bluetooth, to the driver's phone, which streams music over the cell network. Users can preprogram their favorite stations and create song playlists online. The system has a built-in microphone, so that users can make and receive phone calls by pressing a button on the radio.

Product: New Jersey 600i and Hamburg 600i **Cost:** $300 to $400, depending on the stereo's features
Source: www.miroamer.com, www.blaupunkt.com **Company:** miRoamer, Blaupunkt

COURTESY OF MIROAMER AND BLAUPUNKT (RADIO); COURTESY OF NANOGUARDIAN (PILL); JOSHUA SCOTT (BACKUP);

STORAGE

ONE-TOUCH DATA BACKUP

SANDISK'S new hard-drive backup system is a USB thumb drive that plugs into a computer like any other. Unlike other backup systems, however, it doesn't require the installation of new software. The first time you insert the drive into your computer, a window pops up asking you to select a set of folders or a type of file—say, all MP3s. After that, pressing a button on the top of the drive backs up the selected items. The drive uses hardware-based encryption, and accessing data stored on it requires a password. Its capacity ranges from 8 to 64 gigabytes.

Product: Ultra Backup USB Flash Drive
Cost: $39.99 to $199.99, depending on capacity
Source: www.sandiskusb.com
Company: SanDisk

FUEL CELLS

PORTABLE POWER

A NEW fuel cell about the size of a bar of soap gives travelers and backpackers a way to charge iPods or phones when they're not near a power outlet. You activate the cell by squeezing and shaking it; after that, the company claims, it lasts for two or three months and generates about 20 watt-hours of energy, or enough to charge a typical phone five or six times. The power-generating reaction creates a benign by-product akin to soapy water. When the cell is depleted, it can be sent in a preaddressed box to a recycling facility.

■ **Product:** 24/7 Power Pack **Cost:** $49.99 for the initial set (including power cords); $24.99 for replacement cartridges **Source:** www.medistechnologies.com **Company:** Medis

CONSTRUCTION

ENERGY-SAVING INSULATION

AN INSULATION material developed for NASA's space shuttles can save energy here on Earth. Conventional insulation is placed between the structural beams of walls, called studs, but the studs themselves provide a conduit for heat to leak out. Adding Thermablok to the edges of the studs can increase the thermal insulation of a wall by 30 percent. The original material, an aerogel made of fragile silica, was treated with polyester fibers to boost its flexibility without compromising its thermal properties.

■ **Product:** Thermablok **Cost:** $0.99 per foot **Source:** www.thermablok.com **Company:** Acoustiblok

COSMETICS

Eyelash Lengthener

WOMEN who want longer lashes now have an alternative to messy mascara. Latisse, a version of a drug developed for glaucoma, was recently approved by the U.S. Food and Drug Administration to promote eyelash growth. Latisse is dabbed along the base of the eyelashes and must be applied daily, or its lash-thickening effect will wear off. Available only by prescription, it has some potential side effects, including eye redness, itchy eyes, and discoloration of the eyelid.

■ **Product:** Latisse **Cost:** $120 for a 30-day supply **Source:** www.latisse.com **Company:** Allergan

JOSHUA SCOTT (POWER); COURTESY OF ACOUSTIBLOK (INSULATION); COURTESY OF ALLERGAN (EYELASH)

Q&A

PADMASREE WARRIOR

Cisco's CTO tells us what role her federal counterpart should play.

President Obama pledged during his campaign to appoint the nation's first-ever chief technology officer. As CTO of Cisco Systems, a leading maker of the Internet's routing and switching equipment, Padmasree Warrior is a leading candidate for the job.

Warrior sees a federal CTO as helping revitalize the economy by suggesting how information technology can lower health-care costs, revamp the electrical grid, and improve education. Whether or not she ends up in Washington, she is already in a position to help chart the future of the Internet through Cisco's networking strategy and investments. She recently spoke with David Talbot, *Technology Review*'s chief correspondent.

_TR:_ Are you going to be the first national CTO?

Warrior: I can't comment on that.

Your name is all over the media, and you aren't denying it.

[Laughing] That's the media's issue, not mine.

What should the federal CTO do? What should be the priorities?

In terms of the top areas of focus, the first is to work on e-government initiatives, allowing government to be more efficient and open. The second area is to leverage innovation to boost the economy. The third area being talked about is cyber-security.

If you look at President Obama's agenda for technology and the importance he feels it has in terms of putting the United States back as a technology leader—and leveraging technology to boost the economy—the CTO can have a huge impact in that agenda.

But how, for example, does more broadband installation boost the nation's economy, beyond creating one-off construction jobs?

There are many areas we can look at, such as modernizing health care—for example, a doctor could interact with a patient by videoconference—and making the energy grid more efficient with smart-grid technologies. Collaboration, virtual networking, and visual communications will be the e-businesses of the next decade, and this will drive productivity. To do all of that, we need to have broadband connectivity nationwide.

Cisco is planning to make more acquisitions in the area of video. What is the future of networking?

One of the things we see happening is combining video communications with social networking—what we call "visual networking," which will change the way we do business and communicate with our families. Initially, teleconferencing was for business meetings, but we see it moving also into the consumer space and into new areas like health care and education. Some things have to be done to change infrastructure to allow this to happen, like putting intelligence in the network so it can recognize an HD-format video and adjust network characteristics as needed without compromising the quality of service.

Speaking of putting intelligence in the network, Internet security is worse than ever, isn't it?

Security threats have moved from spam, and a few smart people breaking into networks for fun, to becoming far more organized. Now you have bots that you didn't know existed. The whole issue of network security is so much more than having a firewall to protect your device. As we move toward cloud computing, we believe the network has a strong role to play.

What is the future of networks in India and other parts of the developing world?

Video and collaboration are important in emerging as well as developed countries. And more than half of the world is connected via a mobile device. My own view is that very soon the term "mobile Internet" will be redundant. The Internet will be pervasive, mobility will be built into it, and people will expect Internet access no matter where they are and across any device that they possess. As we introduce more personalized applications and high-definition video, we need to think about the network playing an integral role via prioritization, bandwidth, and more intelligence.

IT systems already produce 2 percent of the world's greenhouse-gas emissions. Won't more IT inevitably mean more emissions?

Information technology will drive us to become more sustainable, not less sustainable. Computing will be much more energy efficient. Tele-presence will reduce travel costs and carbon footprints. Applying IT networks will enable the creation of smart buildings and smart transportation systems. And if you look at the network and how many billions of people and how many more billions of devices will connect, we think there is a huge opportunity for the network to play a role in terms of monitoring, managing, and reducing energy consumption.

But can you get rid of skips in voice calls and jitters in streaming video?

Quality of service continues to be important. One of the things we believe, that we've put a lot of effort into ...

Hello?

[A minute later] Hi—sorry, I didn't plug in my cell phone last night! TR

Photograph by HOWARD CAO

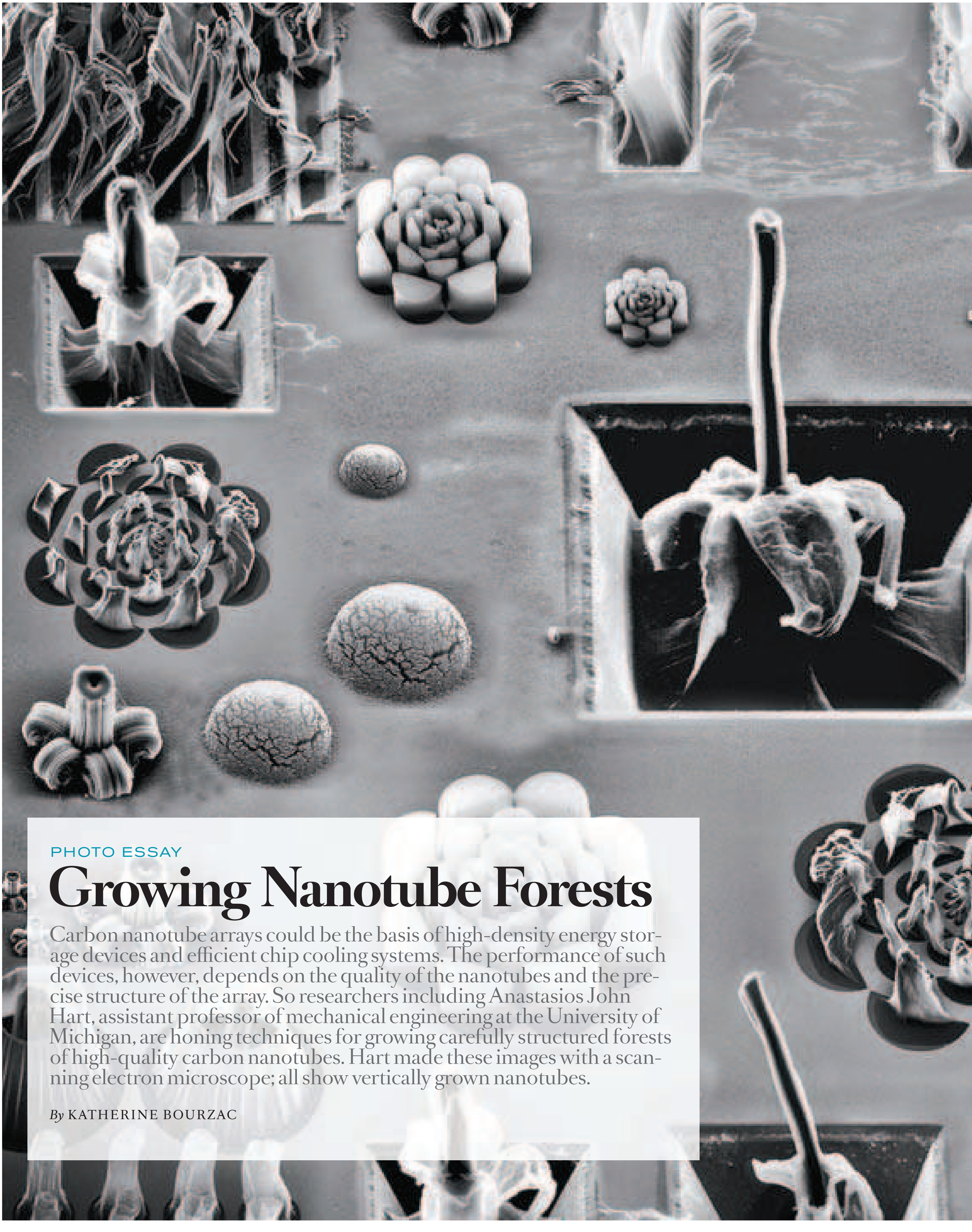
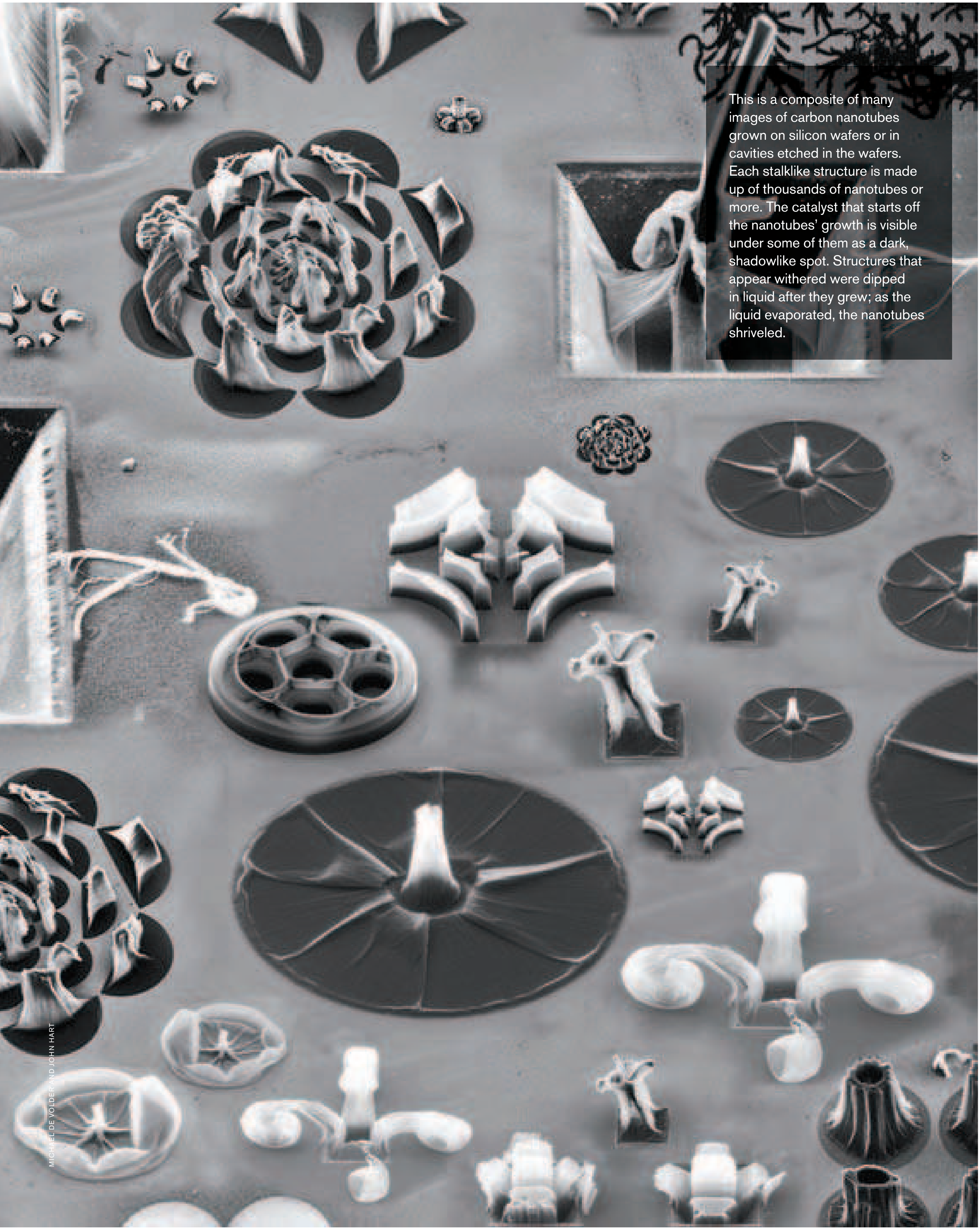


PHOTO ESSAY

Growing Nanotube Forests

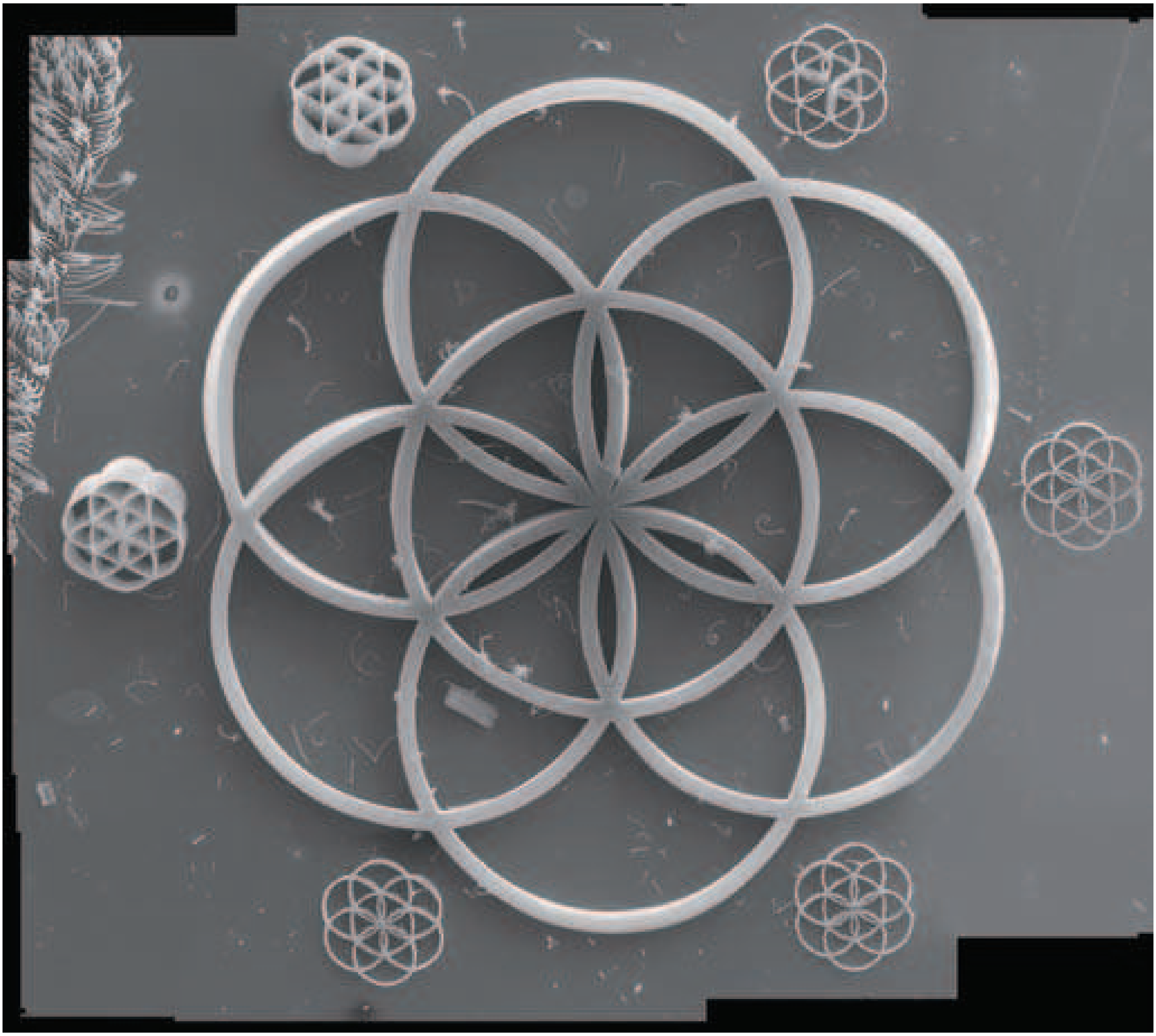
Carbon nanotube arrays could be the basis of high-density energy storage devices and efficient chip cooling systems. The performance of such devices, however, depends on the quality of the nanotubes and the precise structure of the array. So researchers including Anastasios John Hart, assistant professor of mechanical engineering at the University of Michigan, are honing techniques for growing carefully structured forests of high-quality carbon nanotubes. Hart made these images with a scanning electron microscope; all show vertically grown nanotubes.

By KATHERINE BOURZAC



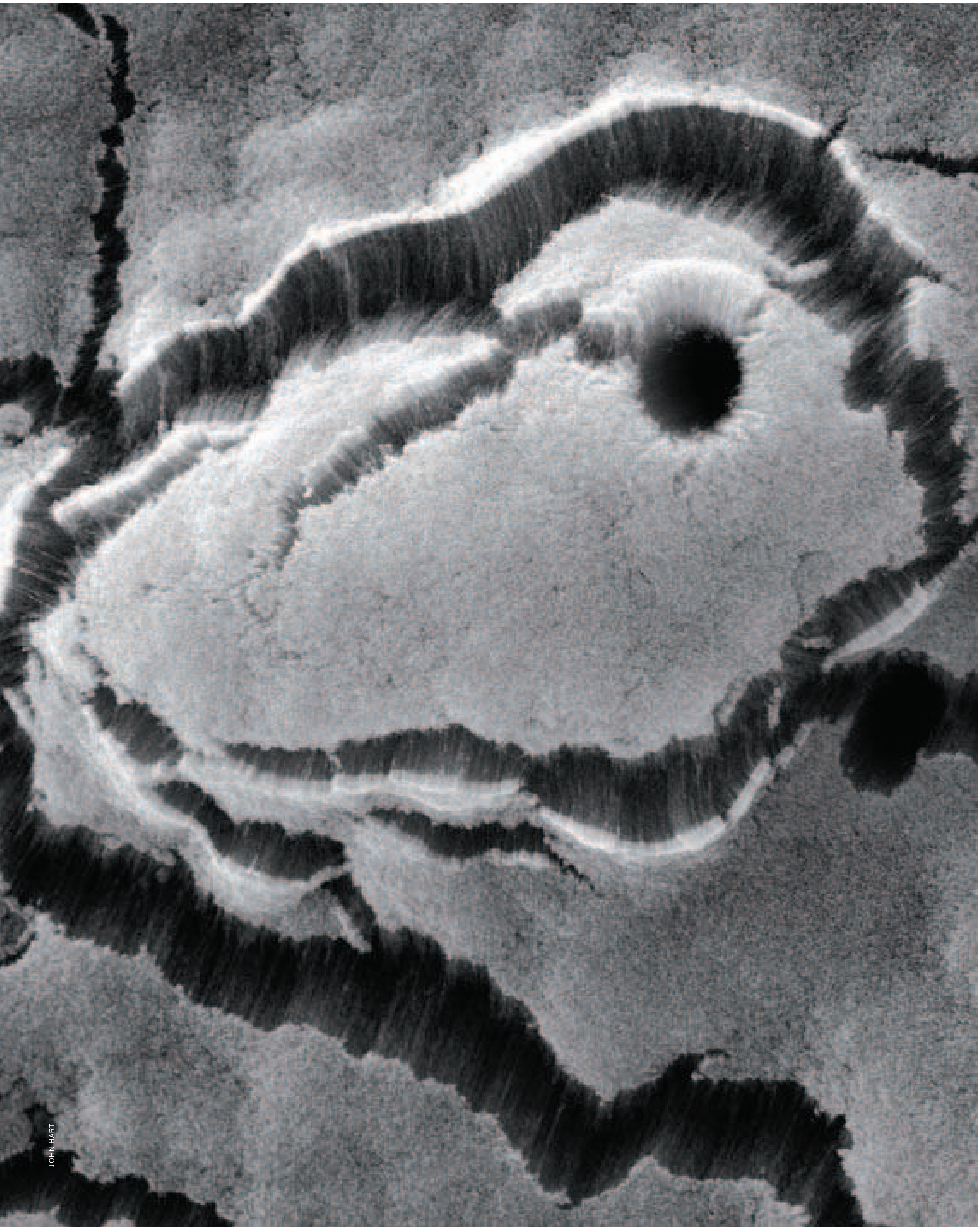
This is a composite of many images of carbon nanotubes grown on silicon wafers or in cavities etched in the wafers. Each stalklike structure is made up of thousands of nanotubes or more. The catalyst that starts off the nanotubes' growth is visible under some of them as a dark, shadowlike spot. Structures that appear withered were dipped in liquid after they grew; as the liquid evaporated, the nanotubes shriveled.

MICHAEL DE VOLDER AND JOHN HART

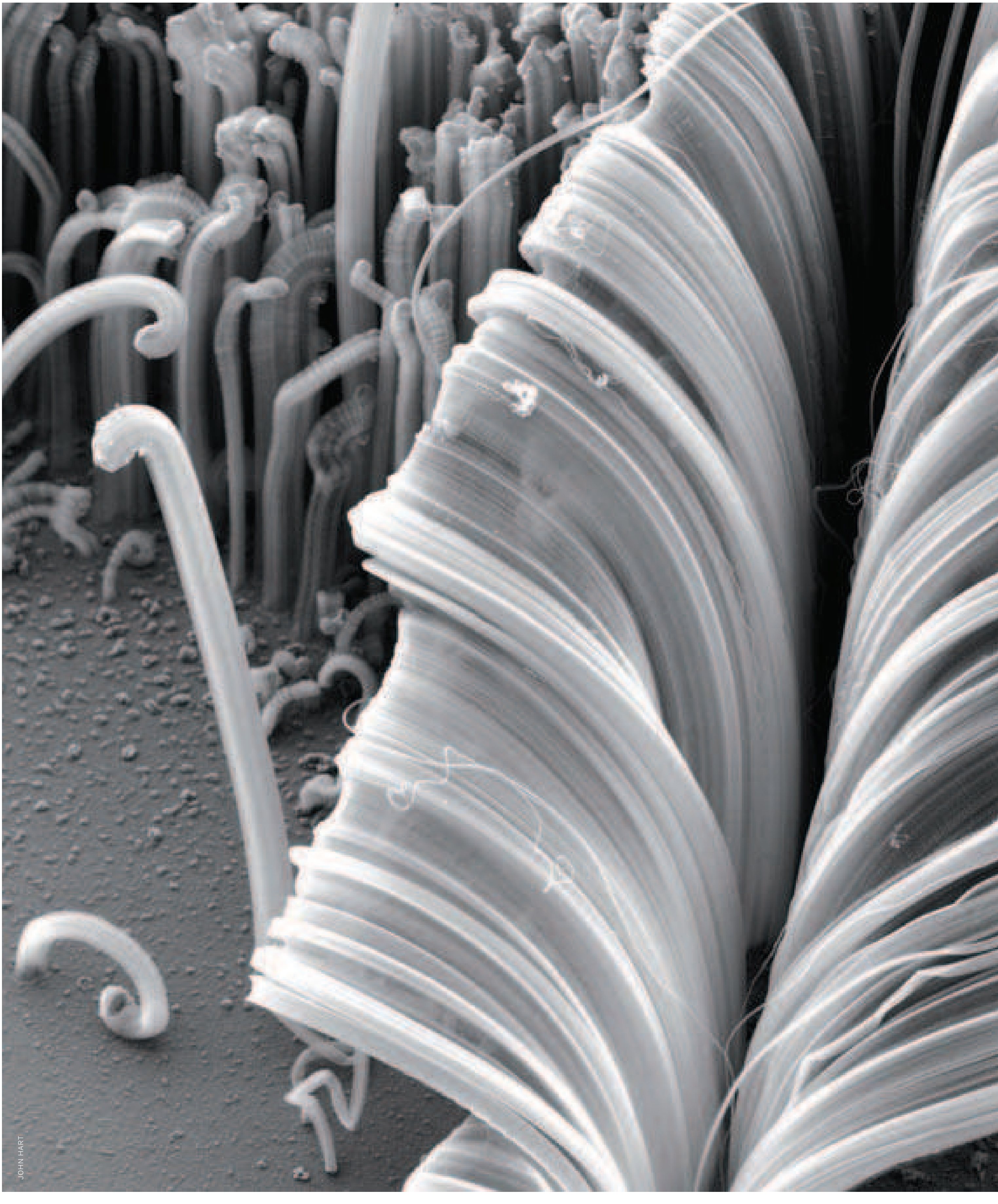


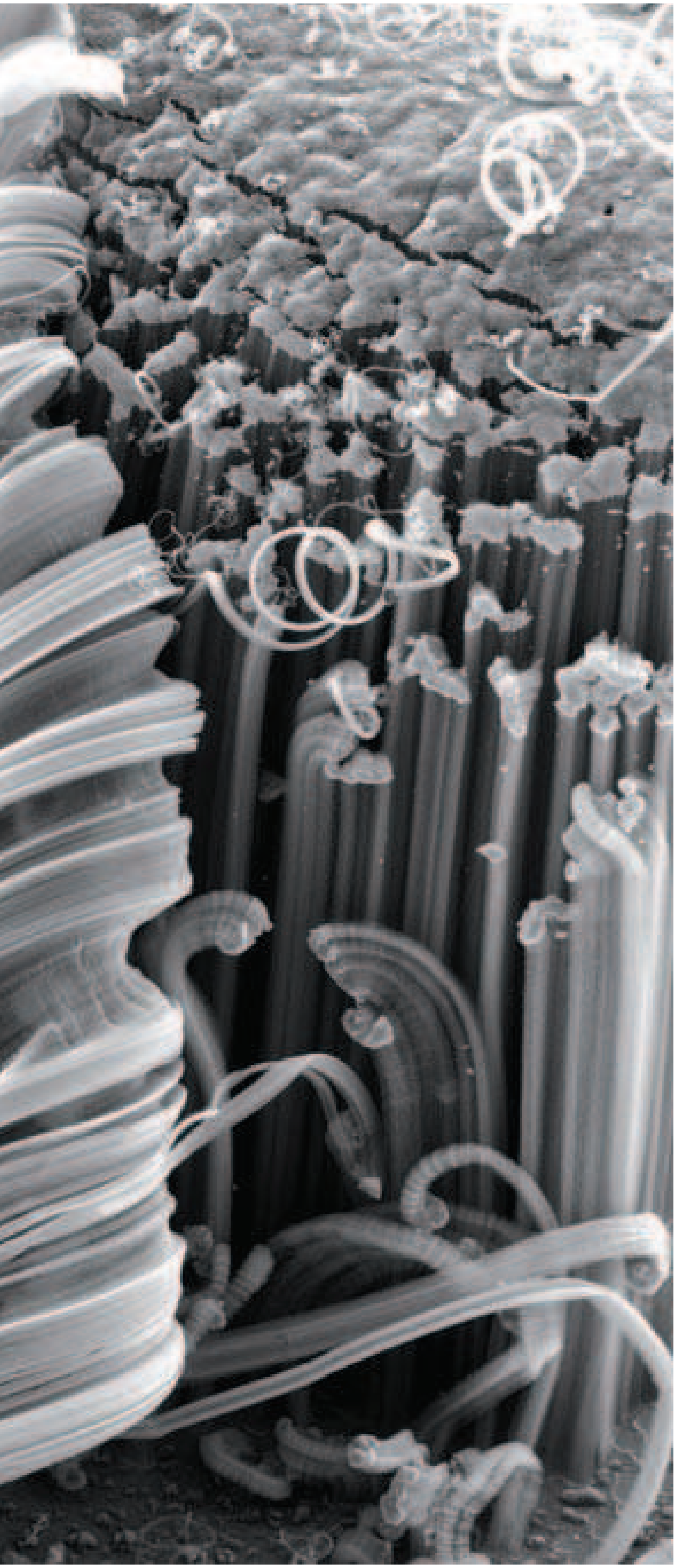
JOHN HART, RYAN WARTENA, FELICE FRANKEL, AND MICHAEL COHEN

The intricate pattern above is made of carbon nanotubes grown on a silicon wafer patterned with a catalyst. The wafer is placed inside a hot chamber that's then filled with ethylene or another carbon-containing gas. On the parts of the wafer coated with the catalyst, the pure tubes of carbon shoot up at great speed; a tree developing at an equivalent rate, Hart says, would be growing at 500 miles per hour. In the much more greatly magnified image on the facing page, small groups of nanotubes, each tube only 5 to10 nanometers in diameter, can be seen bridging cracks in the structure.

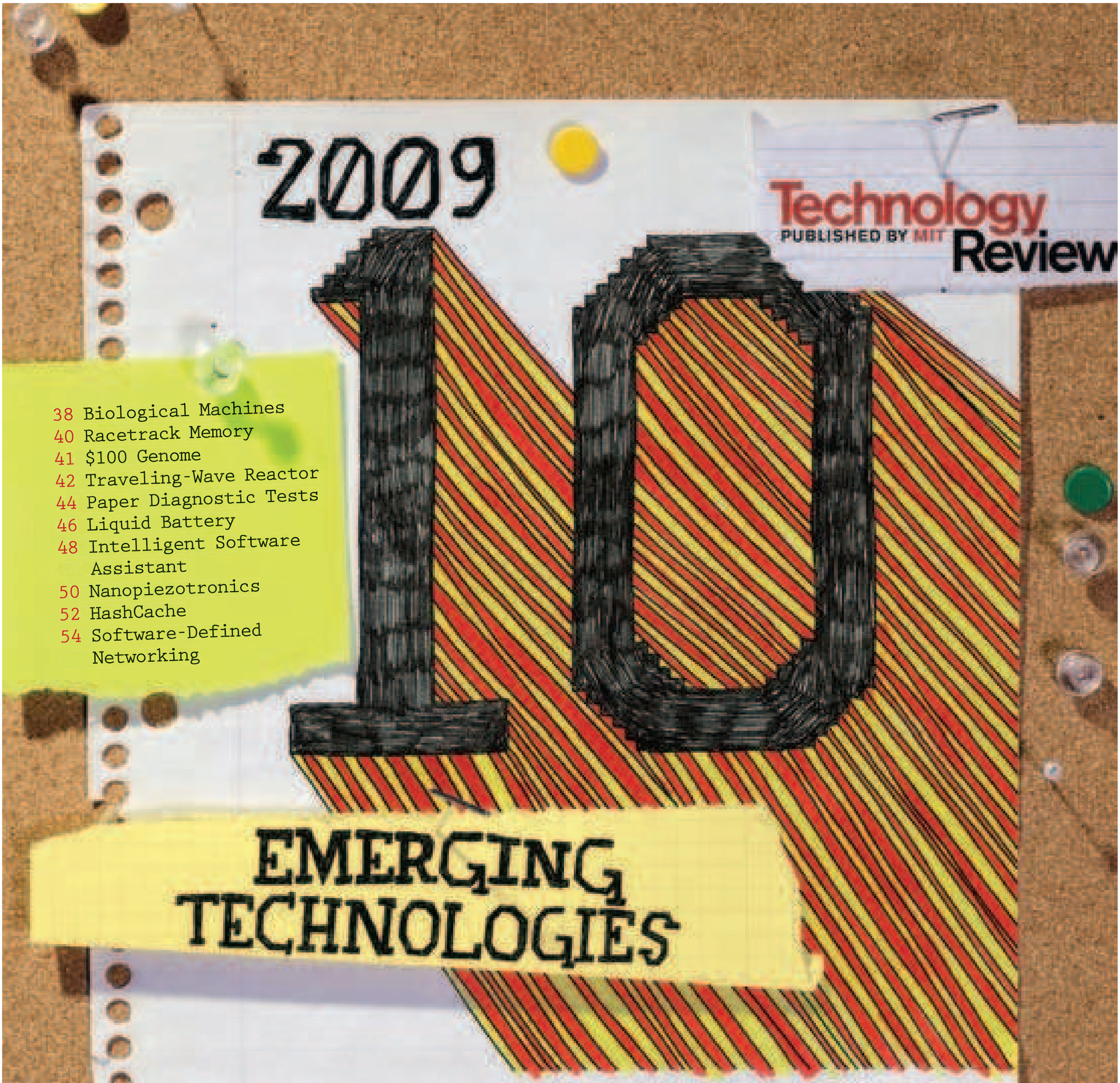


JOHN HART


JOHN HART



Intramolecular forces cause carbon nanotubes to stick to each other. As the nanotubes shoot up, they may tug on their neighbors, speeding their growth. But if reaction conditions aren't optimal—if too much or too little of the catalyst is activated, for example—this stickiness (among other factors) may cause the nanotubes to form tangles, curlicues, fault lines, and other structures like those at left. By exploiting these different tendencies, Hart can make more complex structures like the curved "fingers" above, which might be used as sensing probes.



2009 10 Emerging Technologies

Each year, *Technology Review* chooses 10 emerging technologies with the potential to change lives around the world. Some of this year's choices, such as paper-based medical tests and intelligent software that acts as a personal assistant, could reach the market within a year. Others, like biological machines and nanopiezotronics, could take longer but promise fundamental shifts in fields from computing to medicine, communications to manufacturing. The list includes technologies miniature and massive—from fast, cheap, capacious computer memory to batteries that can store enough energy to power a city. All are technologies that we bet will make a huge impact in the years ahead. —*The Editors*

ART: MIKE PERRY; PHOTOGRAPH: ANNA WOLF

BIOTECH

Biological Machines

Michel Maharbiz's novel interfaces between machines and living systems could give rise to a new generation of cyborg devices.

A giant flower beetle flies about, veering up and down, left and right. But the insect isn't a pest, and it isn't steering its own path. An implanted receiver, microcontroller, microbattery, and six carefully placed electrodes—a payload smaller than a dime and weighing less than a stick of gum—allow an engineer to control the bug wirelessly. By remotely delivering jolts of electricity to its brain and wing muscles, the engineer can make the cyborg beetle take off, turn, or stop midflight.

The beetle's creator, Michel Maharbiz, hopes that his bugs will one day carry sensors or other devices to locations not easily accessible to humans or the terrestrial robots used in search-and-rescue missions. The devices are cheap: materials cost as little as five dollars, and the electronics are easy to build with mostly off-the-shelf components. "They can fly into tiny cracks and could be fitted with heat sensors designed to find injured survivors," says Maharbiz, an assistant professor at the University of California, Berkeley. "You cannot do that now with completely synthetic systems."

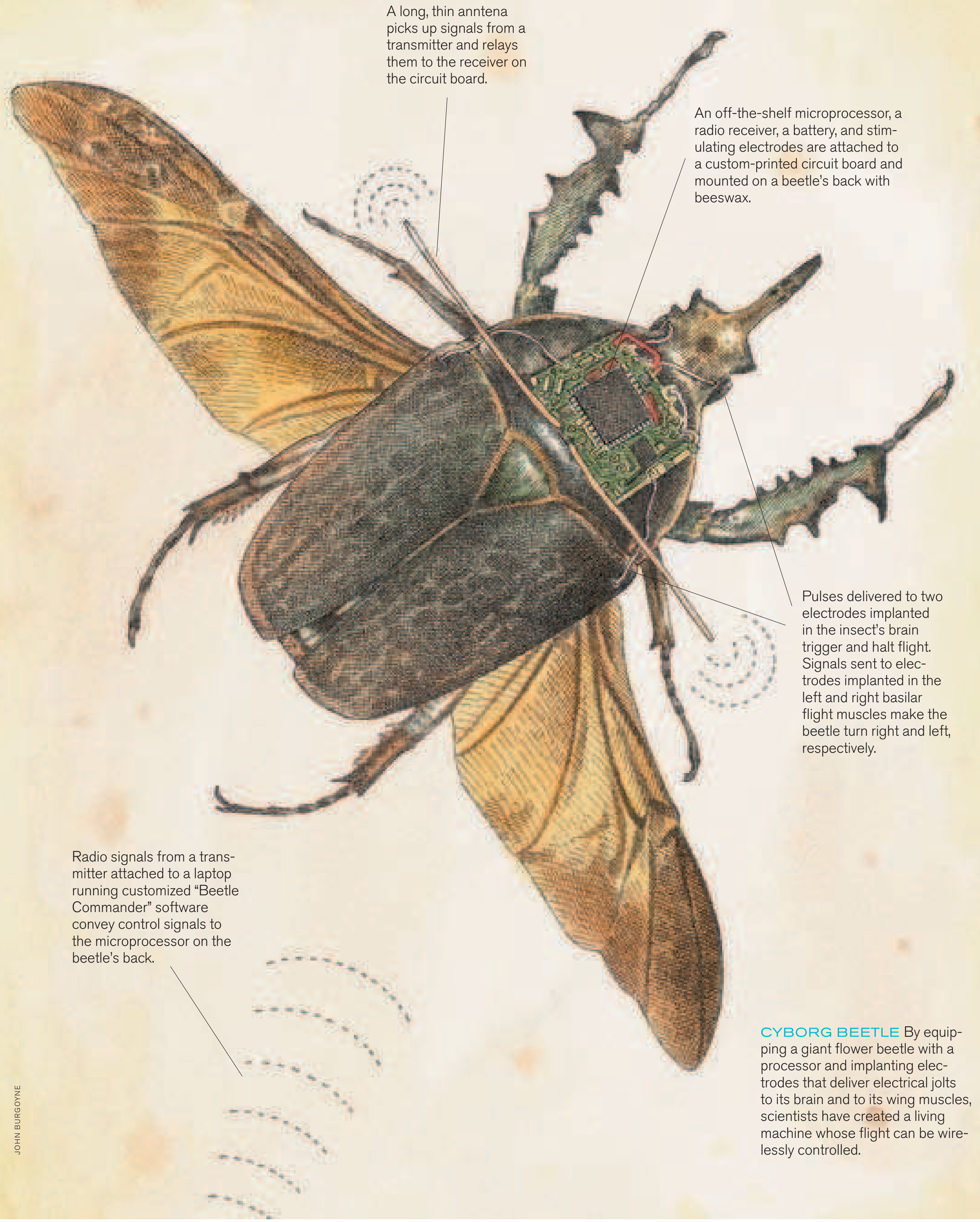
Maharbiz's specialty is designing interfaces between machines and living systems, from individual cells to entire organisms. His goal is to create novel "biological machines" that take advantage of living cells' capacity for extremely low-energy yet exquisitely precise movement, communication, and computation. Maharbiz envisions devices that can collect, manipulate, store, and act on information from their environments. Tissue for replacing damaged organs might be an example, or tables that can repair themselves or reconfigure their shapes on the basis of environmental cues. In 100 years, Maharbiz says, "I bet this kind of machine will be everywhere, derived from cells but completely engineered."

The remote-controlled beetles are an early success story. Beetles integrate visual, mechanical, and chemical information to control flight, all using a modicum of energy—a feat that's almost impossible to reproduce from scratch. In order to deploy a beetle as a useful and sophisticated tool like a search-and-rescue "robot," Maharbiz's team had to create input and output mechanisms that could efficiently communicate with and control the insect's nervous system. Such interfaces are now possible thanks to advances in microfabrication techniques, the availability of ever smaller power sources, and the growing sophistication of microelectromechanical systems (MEMS)—tiny mechanical devices that can be assembled to make things like radios and microcontrollers.

Stuck to the beetle's back is a commercial radio receiver atop a custom-made circuit board. Six electrode stimulators snake from the circuit board into the insect's optic lobes, brain, and left and right basilar flight muscles. A transmitter attached to a laptop running custom software sends messages to the receiver, delivering small electric pulses to the optic lobes to initiate flight and to the left or right flight muscle to trigger a turn. Because the receiver sends very high-level instructions to the beetle's nervous system, it can simply signal the beginning and end of a flight, rather than sending continuous messages to keep the beetle flying.

Others have created interfaces that make it possible to remotely control the movements of rats and other animals. But insects are much smaller, and thus more challenging. Maharbiz is one of the few scientists with a sufficiently deep knowledge of both biology and engineering to successfully mesh an animal's nervous system with MEMS technologies. His team previously modified beetles during the pupal stage, so that their implants are invisible in adulthood—a valuable property if they are to be used in covert missions. The researchers are now working on novel microstimulators and MEMS radio receivers that will allow for more precise neural targeting and even smaller systems.

The cyborg beetle is just one of an array of new technologies incubating in Maharbiz's lab, including microfluidic chips that can deliver controlled amounts of oxygen and other chemicals—even DNA—to individual cells. This kind of system could be used to precisely control the development of cell populations. Ultimately, Maharbiz wants to develop programmable cell-based materials, like those required for the fantastical self-healing table. For now, his team focuses on finding the best ways to manipulate devices such as the beetles. "We want to find out," says Maharbiz, "what are the limits of control?" —*Emily Singer*



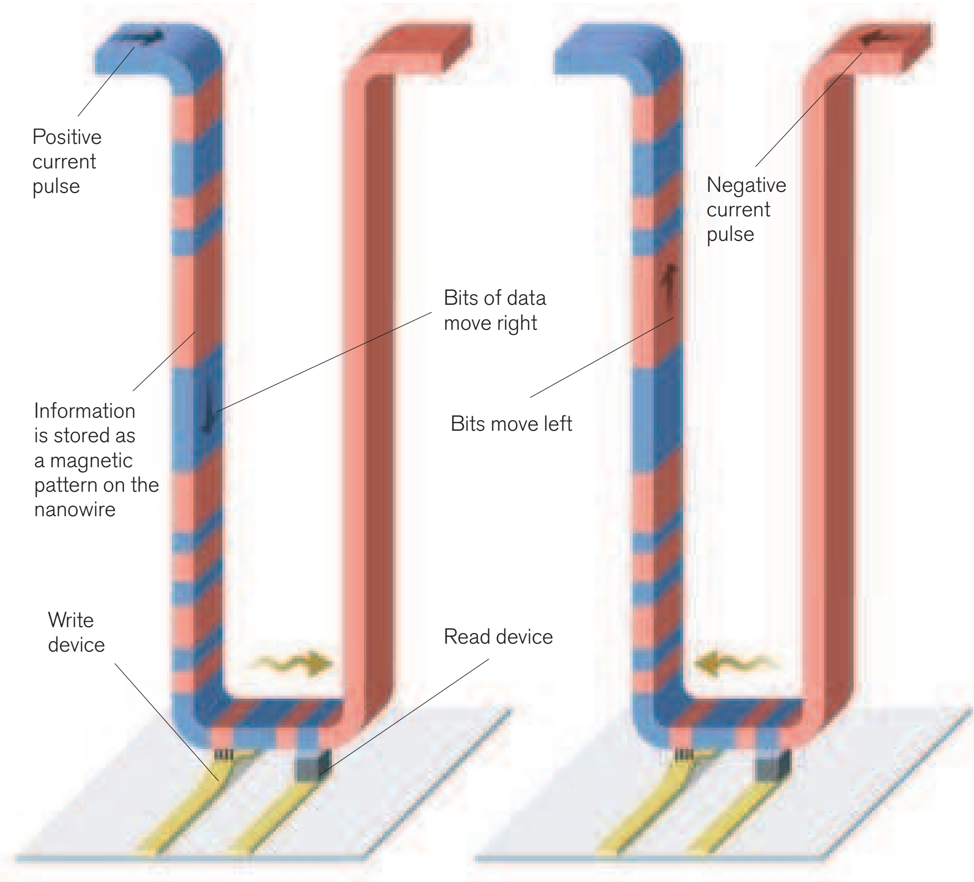
CYBORG BEETLE By equipping a giant flower beetle with a processor and implanting electrodes that deliver electrical jolts to its brain and to its wing muscles, scientists have created a living machine whose flight can be wirelessly controlled.

JOHN BURGOYNE

HARDWARE

Racetrack Memory

Stuart Parkin is using nanowires to create an ultradense, rugged memory chip.



SPEEDING BITS In one implementation of racetrack memory, information is stored on a U-shaped nanowire as a pattern of magnetic regions with different polarities. Applying a spin-polarized current causes the magnetic pattern to speed along the nanowire; the data can be moved in either direction, depending on the direction of the current. A separate nanowire perpendicular to the U-shaped "race-track" writes data by changing the polarity of the magnetic regions. A second device at the base of the track reads the data. Data can be written and read in less than a nanosecond. Racetrack memory using hundreds of millions of nanowires would have the potential to store vast amounts of data.

ARTHUR MOUNT; SOURCE: IBM

When IBM sold its hard-drive business to Hitachi in April 2002, IBM fellow Stuart Parkin wondered what to do next. He had spent his career studying the fundamental physics of magnetic materials, making a series of discoveries that gave hard-disk drives thousands of times more storage capacity. So Parkin set out to develop an entirely new way to store information: a memory chip with the huge storage capacity of a magnetic hard drive, the durability of electronic flash memory, and speed superior to both. He dubbed the new technology "racetrack memory."

Both magnetic disk drives and existing solid-state memory technologies are essentially two-dimensional, Parkin says, relying on a single layer of either magnetic bits or transistors. "Both of these technologies have evolved over the last 50 years, but they've done it by scaling the devices smaller and smaller or developing new means of accessing bits," he says. Parkin sees both technologies reaching their size limits in the coming decades. "Our idea is totally different from any memory that's ever been made," he says, "because it's three-dimensional."

The key is an array of U-shaped magnetic nanowires, arranged vertically like trees in a forest. The nanowires have regions with different magnetic polarities, and the boundaries between the regions represent 1s or 0s, depending on the polarities of the regions on either side. When a spin-polarized current (one in which the electrons' quantum-mechanical "spin" is oriented in a specific direction) passes through the nanowire, the whole magnetic pattern is effectively pushed along, like cars speeding down a racetrack. At the base of the U, the magnetic boundaries encounter a pair of tiny devices that read and write the data *(see "Speeding Bits," above)*.

This simple design has the potential to combine the best qualities of other memory technologies while avoiding their drawbacks. Because racetrack memory stores data in vertical nanowires, it can theoretically pack 100 times as much data into the same area as a flash-chip transistor, and at the same cost. There are no mechanical parts, so it could prove more reliable than a hard drive. Racetrack memory is fast, like the dynamic random-access memory (DRAM) used to hold frequently accessed data in computers, yet it can store information even when the power is off. This is because no atoms are moved in the process of reading and writing data, eliminating wear on the wire.

Just as flash memory ushered in ultrasmall devices that can hold thousands of songs, pictures, and other types of data, racetrack promises to lead to whole new categories of electronics. "An even denser, smaller memory could make computers more compact and more

energy efficient," Parkin says. Moreover, chips with huge data capacity could be shrunk to the size of a speck of dust and sprinkled about the environment in tiny sensors or implanted in patients to log vital signs.

When Parkin first proposed racetrack memory, in 2003, "people thought it was a great idea that would never work," he says. Before last April, no one had been able to shift the magnetic domains along the wire without disturbing their orientations. However, in a paper published that month in *Science*, Parkin's team showed that a spin-polarized current would preserve the original magnetic pattern.

The *Science* paper proved that the concept of racetrack memory is sound, although at the time, the researchers had moved only three bits of data down a nanowire. Last December, Parkin's team successfully moved six bits along the wire. He hopes to reach 10 bits soon, which he says would make racetrack memory competitive with flash storage. If his team can manage 100 bits, racetrack could replace hard drives.

Parkin has already found that the trick to increasing the number of bits a wire can handle is to precisely control its diameter: the narrower and more uniform the wire, the more bits it can hold. Another challenge will be to find the best material for the job: it needs to be one that can survive the manufacturing process and one that allows the magnetic domains to move quickly along the wire, with the least amount of electrical current possible.

If the design proves successful, racetrack memory could replace all other forms of memory, and Parkin will bolster his status as a magnetic-memory genius. After all, his work on giant magnetoresistance, which led to today's high-capacity hard drives, transformed the computing industry. With racetrack memory, Parkin could revamp computing once more.

—*Kate Greene*

BIOTECH

$100 Genome

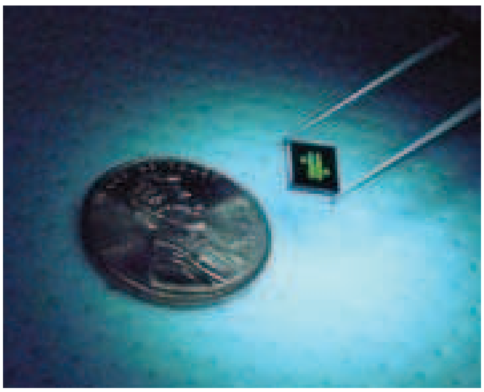
Han Cao has designed a nanofluidic chip that could lower DNA sequencing costs dramatically.

In the corner of the small lab is a locked door with a colorful sign taped to the front: "$100 Genome Room—Authorized Persons Only." BioNanomatrix, the startup that runs the lab, is pursuing what many believe to be the key to personalized medicine: sequencing technology so fast and cheap that an entire human genome can be read in eight hours for $100 or less. With the aid of such a powerful tool, medical treatment could be tailored to a patient's distinct genetic profile.

Despite many experts' doubt that whole-genome sequencing could be done for $1,000, let alone a 10th that much, BioNanomatrix believes it can reach the $100 target in five years. The reason for its optimism: company founder Han Cao has created a chip that uses nanofluidics and a series of branching, ever-narrowing channels to allow researchers, for the first time, to isolate and image very long strands of individual DNA molecules.

If the company succeeds, a physician could biopsy a cancer patient's tumor, sequence all its DNA, and use that information to determine a prognosis and prescribe treatment—all for less than the cost of a chest x-ray. If the ailment is lung cancer, for instance, the doctor could determine the particular genetic changes in the tumor cells and order the chemotherapy best suited to that variant.

Cao's chip, which neatly aligns DNA, is essential to cheaper sequencing because double-stranded



NANOSCALE SORTING A tiny nanofluidic chip (above) is the key to BioNanomatrix's effort to sequence a human genome for just $100. Thousands of branching channels just nanometers wide (top right) untangle very long DNA strands; bright fluorescent labels allow researchers to easily visualize these molecules (bottom right).

COURTESY OF BIONANOMATRIX

DNA, when left to its own devices, winds itself up into tight balls that are impossible to analyze. To sequence even the smallest chromosomes, researchers have had to chop the DNA up into millions of smaller pieces, anywhere from 100 to 1,000 base pairs long. These shorter strands can be sequenced easily, but the data must be pieced back together like a jigsaw puzzle. The approach is expensive and time consuming. What's more, it becomes problematic when the puzzle is as large as the human genome, which consists of about three billion pairs of nucleotides. Even with the most elegant algorithms, some pieces get counted multiple times, while others are omitted completely. The resulting sequence may not include the data most relevant to a particular disease.

In contrast, Cao's chip untangles stretches of delicate double-stranded DNA molecules up to 1,000,000 base pairs long—a feat that researchers had previously thought impossible. The series of branching channels gently prompts the molecules to relax a bit more at each fork, while also acting as a floodgate to help distribute them evenly. A mild electrical charge drives them through the chip, ultimately coaxing them into spaces that are less than 100 nanometers wide. With tens of thousands of channels side by side, the chip allows an entire human genome to flow through in about 10 minutes. The data must still be pieced together, but the puzzle is much smaller (imagine a jigsaw puzzle of roughly 100 pieces versus 10,000), leaving far less room for error.

The chip meets only half the \$100-genome challenge: it unravels DNA but does not sequence it. To achieve that, the company is working with Silicon Valley–based Complete Genomics, which has developed bright, fluorescently labeled probes that bind to the 4,096 possible combinations of six-letter DNA "words." Along with BioNanomatrix's chip, the probes could achieve the lightning-fast sequencing necessary for the \$100 genome. But the probes can't stick to double-stranded DNA, so Complete Genomics will need to figure out how to open up small sections of DNA without uncoupling the entire molecule.

BioNanomatrix is keeping its options open. "At this point, we don't have any exclusive ties to any sequencing chemistry," says Gary Zweiger, the company's vice president of development. "We want to make our chip available to sequencers, and we feel that it is an essential component to driving the costs down to the \$100 level. We can't do it alone, but we feel that they can't do it without this critical component."

Whether or not BioNanomatrix reaches its goal of \$100 sequencing in eight hours, its technology could play an important role in medicine. Because the chips can process long pieces of DNA, the molecules retain information about gene location; they can thus be used to quickly identify new viruses or bacteria causing an outbreak, or to map new genes linked to specific diseases. And as researchers learn more about the genetic variations implicated in different diseases, it might be possible to biopsy tissue and sequence only those genes with variants known to cause disease, says Colin Collins, a professor at the Prostate Center at Vancouver General Hospital, who plans to use BioNanomatrix chips in his lab. "Suddenly," Collins says, "you can sequence extremely rapidly and very, very inexpensively, and provide the patient with diagnosis and prognosis and, hopefully, a drug." *—Lauren Gravitz*

ENERGY

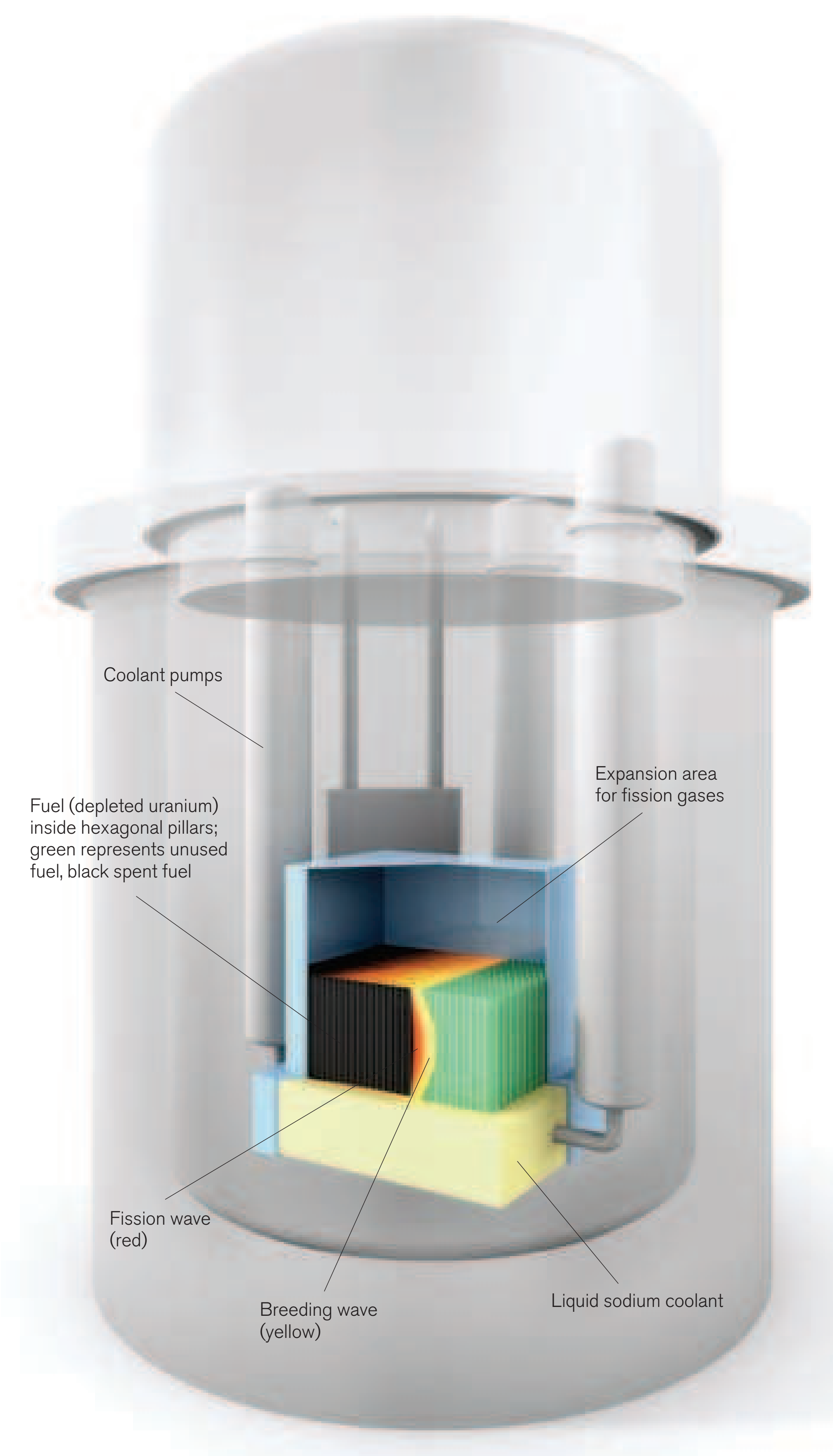
Traveling-Wave Reactor

A new way of fueling reactors could make nuclear power safer and less expensive, says John Gilleland.

Enriching the uranium for reactor fuel and opening the reactor periodically to refuel it are among the most cumbersome and expensive steps in running a nuclear plant. And after spent fuel is removed from the reactor, reprocessing it to recover usable materials has the same drawbacks, plus two more: the risks of nuclear-weapons proliferation and environmental pollution.

These problems are mostly accepted as a given, but not by a group of researchers at Intellectual Ventures, an invention and investment company in Bellevue, WA. The scientists there have come up with a preliminary design for a reactor that requires only a small amount of enriched fuel—that is, the kind whose atoms can easily be split in a chain reaction. It's called a traveling-wave reactor. And while government researchers intermittently bring out new reactor designs, the traveling-wave reactor is noteworthy for having come from something that barely exists in the nuclear industry: a privately funded research company.

As it runs, the core in a traveling-wave reactor gradually converts nonfissile material into the fuel it needs. Nuclear reactors based on such designs "theoretically could run for a couple of hundred years" without refueling, says John



BRYAN CHRISTIE DESIGN

WAVE OF THE FUTURE Unlike today's reactors, a traveling-wave reactor requires very little enriched uranium, reducing the risk of weapons proliferation. The reactor uses depleted-uranium fuel packed inside hundreds of hexagonal pillars (shown in black and green). In a "wave" that moves through the core at only a centimeter per year, this fuel is transformed (or bred) into plutonium, which then undergoes fission. The reaction requires a small amount of enriched uranium (not shown) to get started and could run for decades without refueling. The reactor uses liquid sodium as a coolant; core temperatures are extremely hot—about 550 °C, versus the 330 °C typical of conventional reactors.

ATOMIC SNAPSHOT

How nuclear power is progressing

	Worldwide (including U.S.)	U.S. only
Nuclear plants in operation	439	104
% of total power	14.2	19.4
Plants under construction	42	31*

*no new plants are under construction in the U.S.; this number reflects early proposals by utility companies

Sources: Nuclear Energy Institute; U.S. Nuclear Regulatory Commission

Gilleland, manager of nuclear programs at Intellectual Ventures.

Gilleland's aim is to run a nuclear reactor on what is now waste. Conventional reactors use uranium-235, which splits easily to carry on a chain reaction but is scarce and expensive; it must be separated from the more common, nonfissile uranium-238 in special enrichment plants. Every 18 to 24 months, the reactor must be opened, hundreds of fuel bundles removed, hundreds added, and the remainder reshuffled to supply all the fissile uranium needed for the next run. This raises proliferation concerns, since an enrichment plant designed to make low-enriched uranium for a power reactor differs trivially from one that makes highly enriched material for a bomb.

But the traveling-wave reactor needs only a thin layer of enriched U-235. Most of the core is U-238, millions of pounds of which are stockpiled around the world as leftovers from natural uranium after the U-235 has been scavenged. The design provides "the simplest possible fuel cycle," says Charles W. Forsberg, executive director of the Nuclear Fuel Cycle Project at MIT, "and it requires only one uranium enrichment plant per planet."

The trick is that the reactor itself will convert the uranium-238 into a usable fuel, plutonium-239. Conventional reactors also produce P-239, but using it requires removing the spent fuel,

chopping it up, and chemically extracting the plutonium—a dirty, expensive process that is also a major step toward building an atomic bomb. The traveling-wave reactor produces plutonium and uses it at once, eliminating the possibility of its being diverted for weapons. An active region less than a meter thick moves along the reactor core, breeding new plutonium in front of it.

The traveling-wave idea dates to the early 1990s. However, Gilleland's team is the first to develop a practical design. Intellectual Ventures has patented the technology; the company says it is in licensing discussions with reactor manufacturers but won't name them. Although there are still some basic design issues to be worked out—for instance, precise models of how the reactor would behave under accident conditions—Gilleland thinks a commercial unit could be running by the early 2020s.

While Intellectual Ventures has caught the attention of academics, the commercial industry—hoping to stimulate interest in an energy source that doesn't contribute to global warming—is focused on selling its first reactors in the U.S. in 30 years. The designs it's proposing, however, are essentially updates on the models operating today. Intellectual Ventures thinks that the traveling-wave design will have more appeal a bit further down the road, when a nuclear renaissance is fully under way and fuel supplies look tight.

"We need a little excitement in the nuclear field," says Forsberg. "We have too many people working on 1/10th of 1 percent change."

—Matthew L. Wald

MEDICINE

Paper Diagnostic Tests

George Whitesides has created a cheap, easy-to-use diagnostic test out of paper.

Diagnostic tools that are cheap to make, simple to use, and rugged enough for rural areas could save thousands of lives in poor parts of the world. To make such devices, Harvard University professor George Whitesides is coupling advanced microfluidics with one of humankind's oldest technologies: paper. The result is a versatile, disposable test that can check a tiny amount of urine or blood for evidence of infectious diseases or chronic conditions.

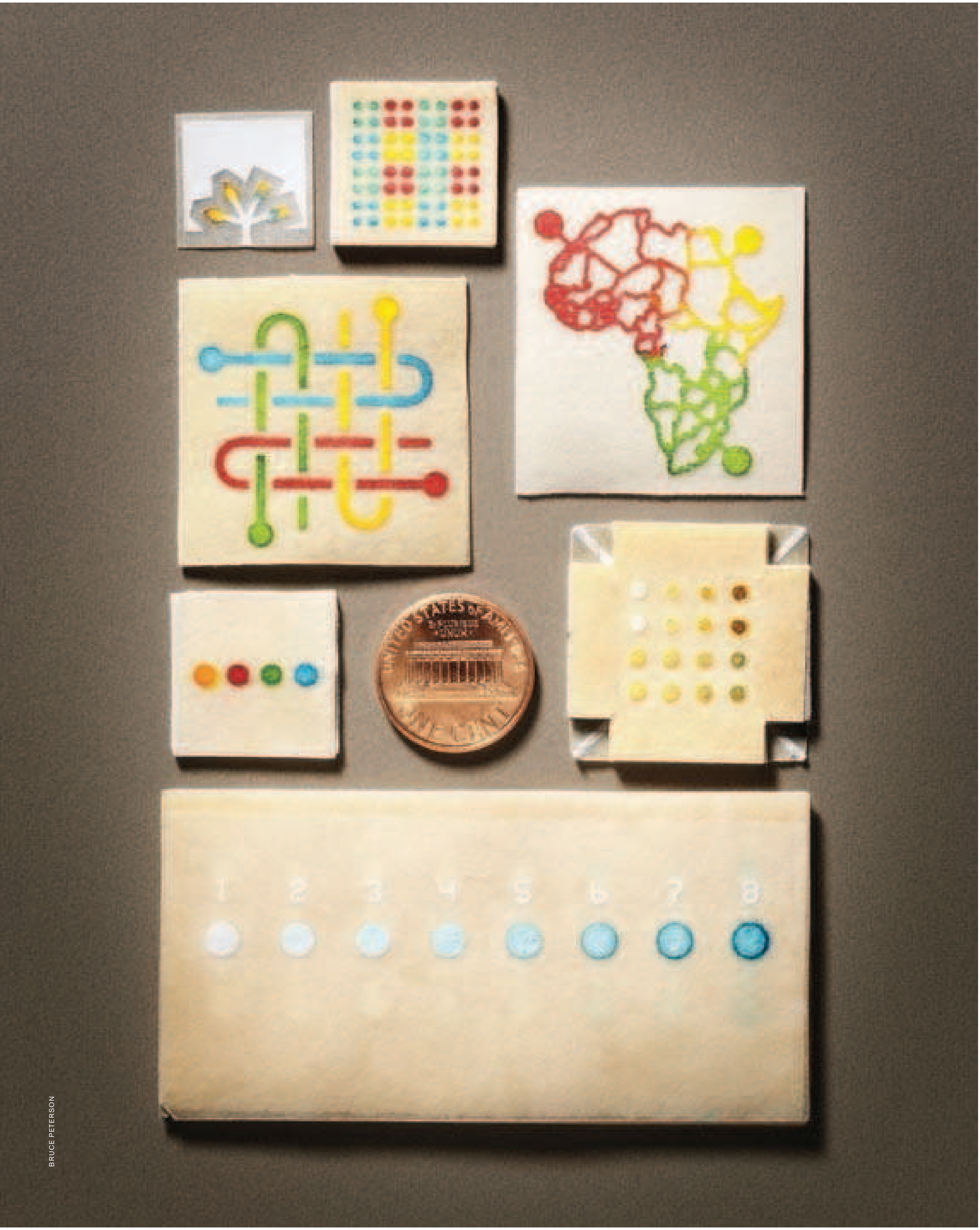
The finished devices are squares of paper roughly the size of postage stamps. The edge of a square is dipped into a urine sample or pressed against a drop of blood, and the liquid moves through channels into testing wells. Depending on the chemicals present, different reactions occur in the wells, turning the paper blue, red, yellow, or green. A reference key is used to interpret the results.

The squares take advantage of paper's natural ability to rapidly soak up liquids, thus circumventing the need for pumps and other mechanical components common in microfluidic devices. The first step in building the devices is to create tiny channels, about a millimeter in width, that direct the fluid to the test wells. Whitesides and his coworkers soak the paper with a light-sensitive photoresist; ultraviolet light causes polymers in the photoresist to cross-link and harden, creating long, waterproof walls wherever the light hits it. The researchers can even create the desired channels and wells by simply drawing on the paper with a black marker and laying it in sunlight. "What we do is structure the flow of fluid in a sheet, taking advantage of the fact that if the paper is the right kind, fluid wicks and hence pulls itself along the channels," says Whitesides. Each well is then brushed with a different solution that reacts with specific molecules in blood or urine to trigger a color change.

Paper is easily incinerated, making it easy to safely dispose of used tests. And while paper-based diagnostics (such as pregnancy tests) already exist, Whitesides's device has an important advantage: a single square can perform many reactions, giving it the potential to diagnose a range of conditions. Meanwhile, its small size means that blood tests require only a tiny sample, allowing a user to simply prick a finger.

Currently, Whitesides is developing a test to diagnose liver failure, which is indicated by elevated levels of certain enzymes in blood. In countries with advanced health care, people who take certain medications undergo regular blood tests to screen for liver problems that the drugs can cause. But people without consistent access to health care do not have that luxury; a paper-based test could give them the same safety margin.

COLOR CHANGE Paper tests, such as those shown here, could make it possible to diagnose a range of diseases quickly and cheaply. A small drop of liquid, such as blood or urine, wicks in through the corner or back of the paper and passes through channels to special testing zones. Substances in these zones react with specific chemicals in the sample to indicate different conditions; results show up as varying colors. These tests are small, simple, and inexpensive.



BRUCE PETERSON

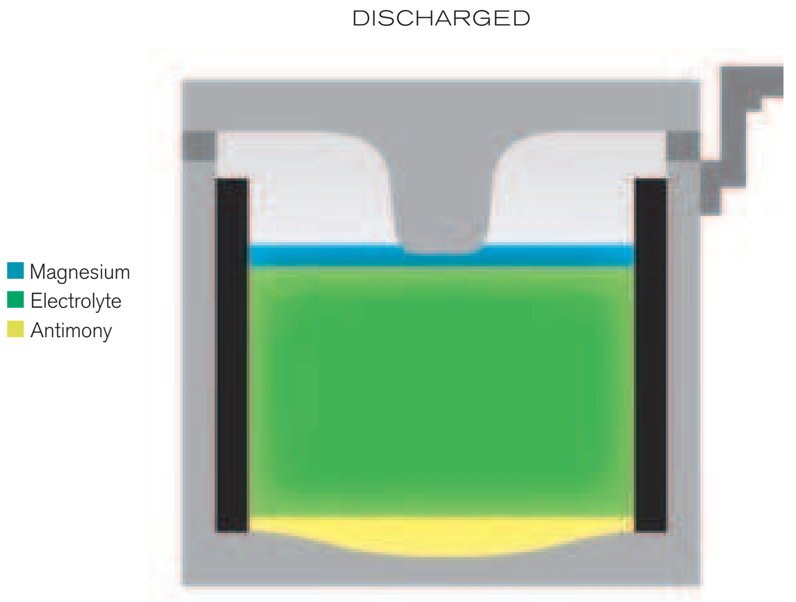
Whitesides also wants to develop tests for infectious diseases such as tuberculosis.

To disseminate the technology, Whitesides cofounded the nonprofit Diagnostics for All in Brookline, MA, in 2007. It plans to deploy the liver function tests in an African country around the end of this year. The team hopes that eventually, people with little medical training can administer the tests and photograph the results with a cell phone. Whitesides envisions a center where technicians and doctors can evaluate the images and send back treatment recommendations.

"This is one of the most deployable devices I have seen," says Albert Folch, an associate professor of bioengineering at the University of Washington, who works with microfluidics. "What is so incredibly clever is that they were able to create photoresist structures embedded inside paper. At the same time, the porosity of the paper acts as the cheapest pump on the planet."

Recently, the Harvard researchers have made the paper chips into a three-dimensional diagnostic device by layering them with punctured pieces of waterproof tape. A drop of liquid can move across channels and into wells on the first sheet, diffuse down through the holes in the tape, and react in test wells on the second paper layer. The ability to perform many more tests and even carry out two-step reactions with a single sample will enable the device to detect diseases (like malaria or HIV) that require more complicated assays, such as those that use antibodies. Results appear after five minutes to half an hour, depending on the test.

The researchers hope the advanced version of the test can eventually be mass produced using the same printing technology that churns out newspapers. Cost for the materials should be three to five cents. At that price, says Folch, the tests "will have a big impact on health care in areas where transportation and energy access is difficult." —*Kristina Grifantini*



1 The molten active components (colored bands) of a new grid-scale storage battery are held in a container that delivers and collects electrical current. Here, the battery is ready to be charged, with positive magnesium and negative antimony ions dissolved in the electrolyte.

ENERGY

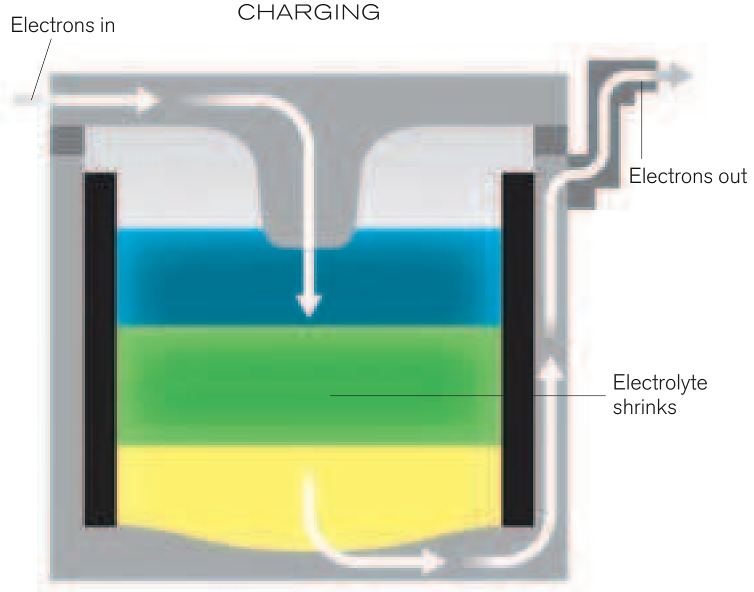
Liquid Battery

Donald Sadoway conceived of a novel battery that could allow cities to run on solar power at night.

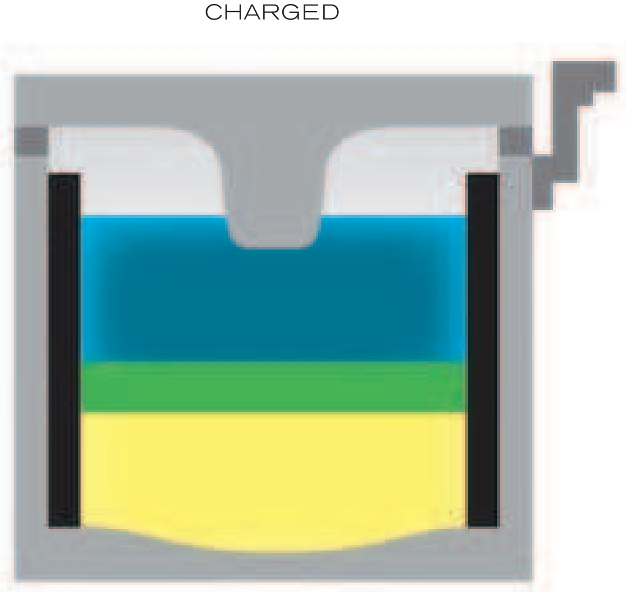
Without a good way to store electricity on a large scale, solar power is useless at night. One promising storage option is a new kind of battery made with all-liquid active materials. Prototypes suggest that these liquid batteries will cost less than a third as much as today's best batteries and could last significantly longer.

The battery is unlike any other. The electrodes are molten metals, and the electrolyte that conducts current between them is a molten salt. This results in an unusually resilient device that can quickly absorb large amounts of electricity. The electrodes can operate at electrical currents "tens of times higher than any [battery] that's ever been measured," says Donald Sadoway, a materials chemistry professor at MIT and one of the battery's inventors. What's more, the materials are cheap, and the design allows for simple manufacturing.

The first prototype consists of a container surrounded by insulating material. The researchers add molten raw materials: antimony on the bottom, an electrolyte such as sodium sulfide in the middle, and magnesium at the top. Since each material has a different density, they naturally remain in distinct layers, which simplifies manufacturing. The container doubles as a current collector, delivering electrons from a power supply, such as solar panels, or carrying them



2 As electric current flows into the cell, the magnesium ions in the electrolyte gain electrons and form magnesium metal, which joins the molten magnesium electrode. At the same time, the antimony ions give up electrons to form metal atoms at the opposite electrode.



3 As metal forms, the electrolyte shrinks and the electrodes grow, an unusual property for batteries. During discharge, the process is reversed, and the metal atoms become ions again.

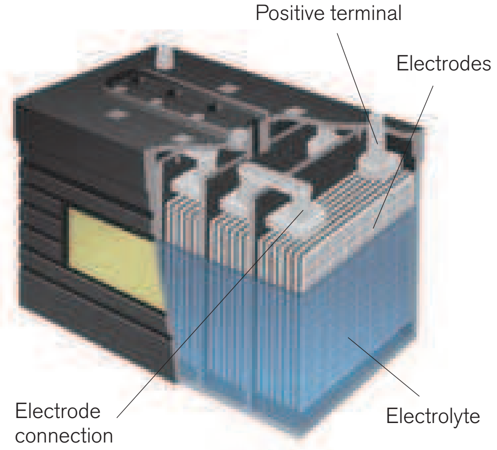
away to the electrical grid to supply electricity to homes and businesses.

As power flows into the battery, magnesium and antimony metal are generated from magnesium antimonide dissolved in the electrolyte. When the cell discharges, the metals of the two electrodes dissolve to again form magnesium antimonide, which dissolves in the electrolyte, causing the electrolyte to grow larger and the electrodes to shrink *(see above)*.

Sadoway envisions wiring together large cells to form enormous battery packs. One big enough to meet the peak electricity demand in New York City—about 13,000 megawatts—would fill nearly 60,000 square meters. Charging it would require solar farms of unprecedented size, generating not only enough electricity to meet daytime power needs but enough excess power to charge the batteries for nighttime demand. The first systems will probably store energy produced during periods of low electricity demand for use during peak demand, thus reducing the need for new power plants and transmission lines.

Many other ways of storing energy from intermittent power sources have been proposed, and some have been put to limited use. These range from stacks of lead-acid batteries to systems that pump water uphill during the day and let it flow back to spin generators at night. The liquid battery has the advantage of being cheap, long-lasting, and (unlike options such as pumping water) useful in a wide range of places. "No one had been able to get their arms around the problem of energy storage on a massive scale for the power grid," says Sadoway. "We're literally looking at a battery capable of storing the grid."

Since creating the initial prototypes, the researchers have switched the metals and salts used; it wasn't possible to dissolve magnesium antimonide in the electrolyte at high concentrations, so the first prototypes were too big to be practical. (Sadoway won't identify the new materials but says they work along the same principles.) The team hopes that a commercial version of the battery will be available in five years. —*Kevin Bullis*



CONVENTIONAL BATTERY

Ordinary batteries use at least one solid active material. In the lead-acid battery shown here, the electrodes are solid plates immersed in a liquid electrolyte. Solid materials limit the conductivity of batteries and therefore the amount of current that can flow through them. They're also vulnerable to cracking, disintegrating, and otherwise degrading over time, which reduces their useful lifetimes.

ARTHUR MOUNT

SOFTWARE

Intelligent Software Assistant

Adam Cheyer is leading the design of powerful software that acts as a personal aide.

Search is the gateway to the Internet for most people; for many of us, it has become second nature to distill a task into a set of keywords that will lead to the required tools and information. But Adam Cheyer, cofounder of Silicon Valley startup Siri, envisions a new way for people to interact with the services available on the Internet: a "do engine" rather than a search engine. Siri is working on virtual personal-assistant software, which would help users complete tasks rather than just collect information.

Cheyer, Siri's vice president of engineering, says that the software takes the user's context into account, making it highly useful and flexible. "In order to get a system that can act and reason, you need to get a system that can interact and understand," he says.

Siri traces its origins to a military-funded artificial-intelligence project called CALO, for "cognitive assistant that learns and organizes," that is based at the research institute SRI International. The project's leaders–including Cheyer–combined traditionally isolated approaches to artificial intelligence to try to create a personal-assistant program that improves by interacting with its user. Cheyer, while still at SRI, took a team of engineers aside and built a sample consumer version; colleagues finally persuaded him to start a company based on the prototype. Siri licenses its core technology from SRI.

Mindful of the sometimes spectacular failure of previous attempts to create a virtual personal assistant, Siri's founders have set their sights conservatively. The initial version, to be released this year, will be aimed at mobile users and will perform only specific types of functions, such as helping make reservations at restaurants, check flight status, or plan weekend activities. Users can type or speak commands in casual sentences, and the software deciphers their intent from the context. Siri is connected to multiple online services, so a quick interaction with it can accomplish several small tasks that would normally require visits to a number of websites. For example, a user can ask Siri to find a midpriced Chinese restaurant in a specific part of town and make a reservation there.

Recent improvements in computer processor power have been essential in bringing this level of sophistication to a consumer product, Cheyer says. Many of CALO's abilities still can't be crammed into such products. But the growing power of mobile phones and the increasing speed of networks make it possible to handle some of the processing at Siri's headquarters and pipe the results back to users, allowing the software to take on tasks that just couldn't be done before.

"Search does what search does very well, and that's not going anywhere anytime soon," says Dag Kittlaus, Siri's cofounder and CEO. "[But] we believe that in five years, everyone's going to have a virtual assistant to which they delegate a lot of the menial tasks."

While the software will be intelligent and useful, the company has no aspiration to make it seem human. "We think that we can create an incredible experience that will help you be more efficient in your life, in solving problems and the tasks that you do," Cheyer says. But Siri is always going to be just a tool, not a rival to human intelligence: "We're very practical minded." *–Erica Naone*

WEEKEND PLANS

Siri cofounder Tom Gruber volunteered Adam Cheyer to participate in a conversation with the software. Gruber explains the artificial-intelligence tasks behind its responses.

1 "The user can ask a broad question like this because Siri has information that gives clues about what the user intends. For example, the software might store data about the user's location, schedule, and past activities. Siri can deal with open-ended questions within specific areas, such as entertainment or travel."

2 "Siri pulls information relevant to the user's question from a variety of Web services and tools. In this case, it checks the weather, event listings, and directories of local attractions and uses machine learning to select certain options based on the user's past preferences. Siri can connect to various Web applications and then integrate the results into a single response."

3 "Siri interprets this reply in the context of the existing conversation, using it to refine the user's request."

4 "The software offers specific suggestions based on the user's personal preferences and its ability to categorize. Because Siri is task-oriented, rather than a search engine, it offers to buy tickets that the user selects."

5 "By now, the conversation has narrowed enough that all the user has to do is click on his choice."

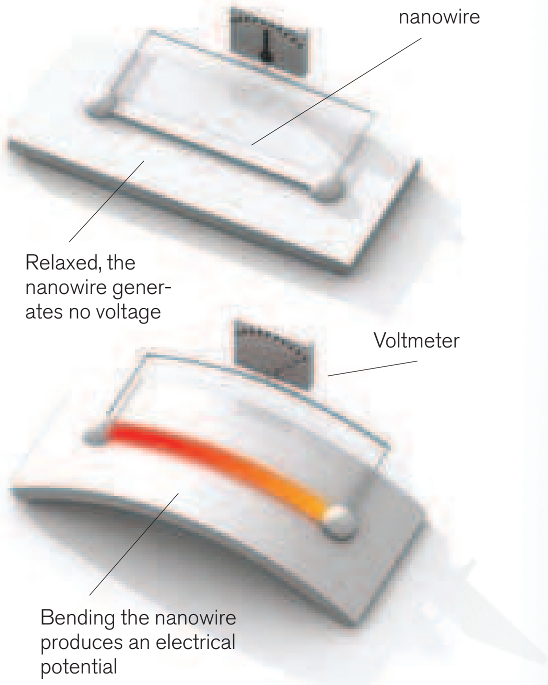
6 "Siri compiles information about the event, such as band members, directions, and prices, and structures it in a logical way. It also handles the task of finding out what's available and getting the tickets."


1 What can I do this weekend?
2 It looks like it will be good weather this weekend near your home in San Francisco. There is a music festival in town, some great parks and beaches, and a ball game at the stadium.
3 Music
4 OK, there is a blues festival in the park, a Latin rock act is playing at the Warfield, and some local bands playing in clubs. I can get you tickets for these.
5 Latin rock act (by clicking)
6 The band is called Voices of Latin Rock (see details below). The 8:00 show is sold out. I can get you tickets for the 10:00 show. How many people in your party?
HOWARD CAO

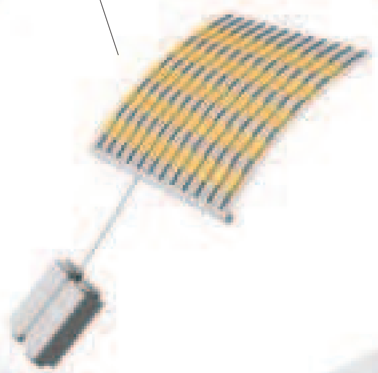
NANOTECH

Nanopiezotronics

Zhong Lin Wang thinks piezoelectric nanowires could power implantable medical devices and serve as tiny sensors.



PIEZOELECTRIC WIRES The mechanical stress produced by bending a zinc oxide nanowire creates an electrical potential across the wire. This drives current through a circuit. The conversion of mechanical energy to electrical energy is called the piezoelectric effect. It's harnessed in the devices on the facing page, which might be made from the nanowires.



NANOGENERATOR Arrays of zinc oxide nanowires packaged in a thin polymer film generate electrical current when flexed. The nanogenerator could be embedded in clothing and used to convert the rustling of fabric into current to power portable devices such as cell phones.

Nanoscale sensors are exquisitely sensitive, very frugal with power, and, of course, tiny. They could be useful in detecting molecular signs of disease in the blood, minute amounts of poisonous gases in the air, and trace contaminants in food. But the batteries and integrated circuits necessary to drive these devices make them difficult to fully miniaturize. The goal of Zhong Lin Wang, a materials scientist at Georgia Tech, is to bring power to the nano world with minuscule generators that take advantage of piezoelectricity. If he succeeds, biological and chemical nano sensors will be able to power themselves.

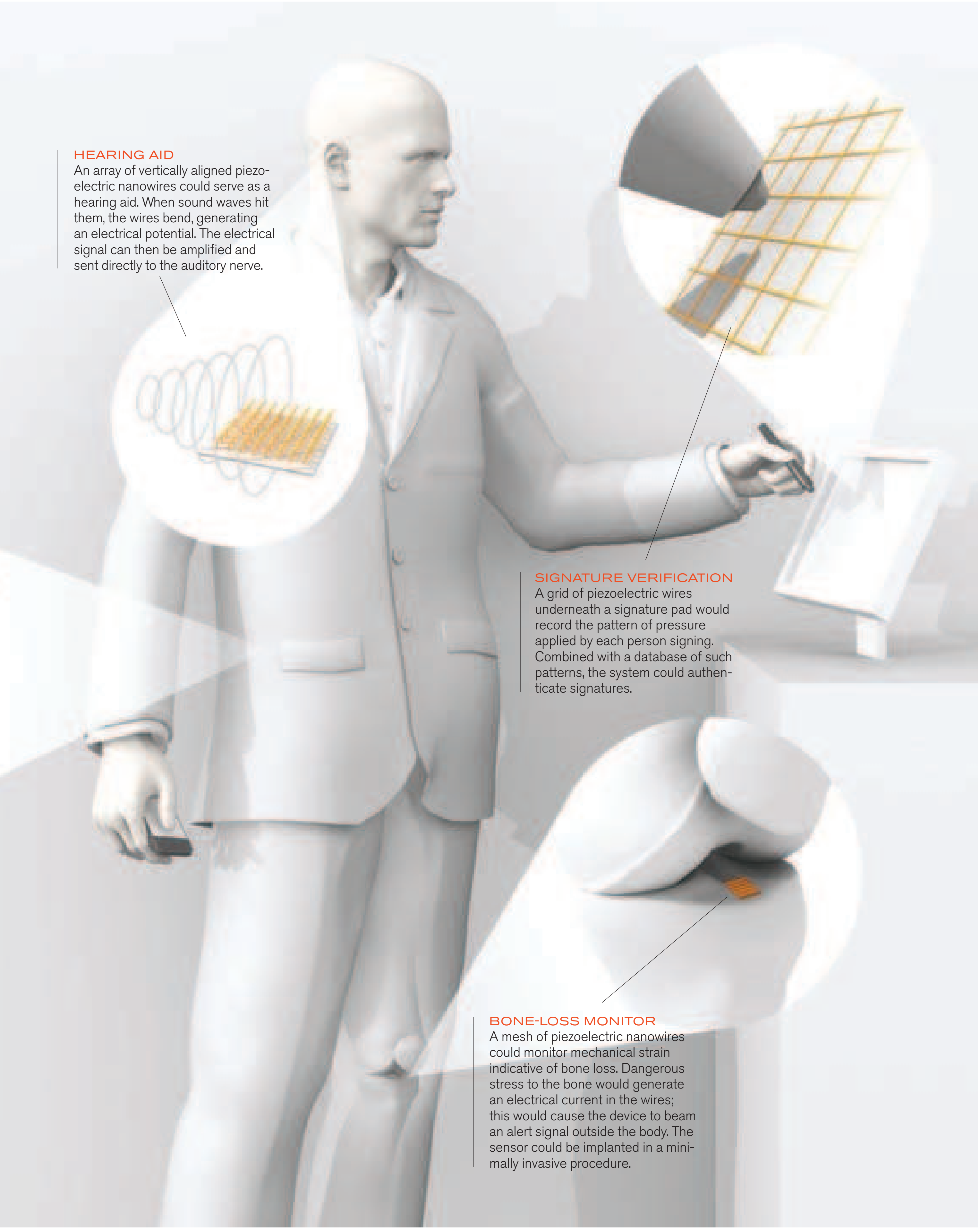
The piezoelectric effect—in which crystalline materials under mechanical stress produce an electrical potential—has been known of for more than a century. But in 2005, Wang was the first to demonstrate it at the nanoscale by bending zinc oxide nanowires with the probe of an atomic-force microscope. As the wires flex and return to their original shape, the potential produced by the zinc and oxide ions drives an electrical current. The current that Wang coaxed from the wires in his initial experiments was tiny; the electrical potential peaked at a few millivolts. But Wang rightly suspected that with enough engineering, he could design a practical nanoscale power source by harnessing the tiny vibrations all around us—sound waves, the wind, even the turbulence of blood flow over an implanted device. These subtle movements would bend nanowires, generating electricity.

Last November, Wang embedded zinc oxide nanowires in a layer of polymer; the resulting sheets put out 50 millivolts when flexed. This is a major step forward in powering tiny sensors.

And Wang hopes that these generators could eventually be woven into fabric; the rustling of a shirt could generate enough power to charge the batteries of devices like iPods. For now, the nanogenerator's output is too low for that. "We need to get to 200 millivolts or more," says Wang. He'll get there by layering the wires, he says, though it might take five to ten more years of careful engineering.

Meanwhile, Wang has demonstrated the first components for a new class of nanoscale sensors. Nanopiezotronics, as

BRYAN CHRISTIE DESIGN


HEARING AID
An array of vertically aligned piezoelectric nanowires could serve as a hearing aid. When sound waves hit them, the wires bend, generating an electrical potential. The electrical signal can then be amplified and sent directly to the auditory nerve.
SIGNATURE VERIFICATION
A grid of piezoelectric wires underneath a signature pad would record the pattern of pressure applied by each person signing. Combined with a database of such patterns, the system could authenticate signatures.
BONE-LOSS MONITOR
A mesh of piezoelectric nanowires could monitor mechanical strain indicative of bone loss. Dangerous stress to the bone would generate an electrical current in the wires; this would cause the device to beam an alert signal outside the body. The sensor could be implanted in a minimally invasive procedure.

he calls this technology, exploit the fact that zinc oxide nanowires not only exhibit the piezoelectric effect but are semiconductors. The first property lets them act as mechanical sensors, because they produce an electrical response to mechanical stress. The second means that they can be used to make the basic components of integrated circuits, including transistors and diodes. Unlike traditional electronic components, nanopiezotronics don't need an external source of electricity. They generate their own when exposed to the same kinds of mechanical stresses that power nanogenerators.

Freeing nanoelectronics from outside power sources opens up all sorts of possibilities. A nanopiezotronic hearing aid integrated with a nanogenerator might use an array of nanowires, each tuned to vibrate at a different frequency over a large range of sounds. The nanowires would convert sounds into electrical signals and process them so that they could be conveyed directly to neurons in the brain. Not only would such implanted neural prosthetics be more compact and more sensitive than traditional hearing aids, but they wouldn't need to be removed so their batteries could be changed. Nanopiezotronic sensors might also be used to detect mechanical stresses in an airplane engine; just a few nanowire components could monitor stress, process the information, and then communicate the relevant data to an airplane's computer. Whether in the body or in the air, nano devices would at last be set loose in the world all around us. —*Katherine Bourzac*

OLIVIER ASSELIN/WPN

INTERNET

HashCache

Vivek Pai's new method for storing Web content could make Internet access more affordable around the world.

Throughout the developing world, scarce Internet access is a more conspicuous and stubborn aspect of the digital divide than a dearth of computers. "In most places, networking is more expensive—not only in relative terms but even in absolute terms—than it is in United States," says Vivek Pai, a computer scientist at Princeton University. Often, even universities in poor countries can afford only low-bandwidth connections; individual users receive the equivalent of a fraction of a dial-up connection. To boost the utility of these connections, Pai and his group created HashCache, a highly efficient method of caching—that is, storing frequently accessed Web content on a local hard drive instead of using

CACHE COW

A one-terabyte hard-disk cache could give students in a poor country much faster access to Web content. But operating such a cache can be expensive. HashCache offers a way to cut costs.

Elements needed for a Web cache	Conventional caching solution	HashCache
Storage disk/cost	1 terabyte/$100	1 terabyte/$100
RAM for index and related applications	14 gigabytes	256 megabytes
Computer with adequate RAM	$2,800	$200 to $300
Power to run computer	300 watts	30 watts
Monthly cost of round-the-clock power (10 cents per kilowatt-hour)	$21.60	$2.16
Total cost of setup and two years of operation	$3,418.40	$351.84 to $451.84

CLOSING THE DIVIDE Students surf the Web at Ghana's Kokrobitey Institute, a conference center with an Internet connection only about four times as fast as dial-up. The link is enhanced by Princeton's low-cost, low-power HashCache technology, which stores frequently accessed Web content.

precious bandwidth to retrieve the same information repeatedly.

Despite the Web's protean nature, a surprising amount of its content doesn't change often or by very much. But current caching technologies require not only large hard disks to hold data but also lots of random-access memory (RAM) to store an index that contains the "address" of each piece of content on the disk. RAM is expensive relative to hard-disk capacity, and it works only when supplied with electricity—which, like bandwidth, is often both expensive and scarce in the developing world.

HashCache abolishes the index, slashing RAM and electricity requirements by roughly a factor of 10. It starts by transforming the URL of each stored Web "object"—an image, graphic, or block of text on a Web page—into a shorter number, using a bit of math called a hash function. While most other caching systems do this, they also store each hash number in a RAM-hogging table that correlates it with a hard-disk memory address. Pai's technology can skip this step because it uses a novel hash function: the number that the function produces defines the spot on the disk where the corresponding Web object can be found. "By using the hash to directly compute the location, we can get rid of the index entirely," Pai says.

To be sure, some RAM is still needed, but only enough to run the hash function and to actually retrieve a specific Web object, Pai says. Though still at a very early stage of development, HashCache is being field-tested at the Kokrobitey Institute in Ghana and Obafemi Awolowo University in Nigeria.

The technology ends a long drought in fundamental caching advances, says Jim Gettys, a coauthor of the HTTP specification that serves as the basis of Internet communication. While it's increasingly feasible for a school in a poor country to buy hundreds of gigabytes of hard-disk memory, Gettys says, those same schools—if they use today's best available software—can typically afford only enough RAM to support tens of gigabytes of cached content. With HashCache, a classroom equipped with pretty much any kind of computers, even castoff PCs, could store and cheaply access one terabyte of Web data. That's enough to store all of Wikipedia's content, for example, or all the coursework freely available from colleges such as Rice University and MIT.

Even with new fiber-optic cables connecting East Africa to the Internet, thousands of students at some African universities share connections that have roughly the same speed as a home DSL line, says Ethan Zuckerman, a fellow at the Berkman Center for Internet and Society at Harvard University. "These universities are extremely bandwidth constrained," he says. "All their students want to have computers but almost never have sufficient bandwidth. This innovation makes it significantly cheaper to run a very large caching server."

Pai plans to license HashCache in a way that makes it free for nonprofits but leaves the door open to future commercialization. And that means that it could democratize Internet access in wealthy countries, too. *—David Talbot*

INTERNET

Software-Defined Networking

Nick McKeown believes that remotely controlling network hardware with software can bring the Internet up to speed.

For years, computer scientists have dreamed up ways to improve networks' speed, reliability, energy efficiency, and security. But their schemes have generally remained lab projects, because it's been impossible to test them on a large enough scale to see if they'd work: the routers and switches at the core of the Internet are locked down, their software the intellectual property of companies such as Cisco and Hewlett-Packard.

Frustrated by this inability to fiddle with Internet routing in the real world, Stanford computer scientist Nick McKeown and colleagues developed a standard called OpenFlow that essentially opens up the Internet to researchers, allowing them to define data flows using software—a sort of "software-defined networking." Installing a small piece of OpenFlow firmware (software embedded in hardware) gives engineers access to flow tables, rules that tell switches and routers how to direct network traffic. Yet it protects the proprietary routing instructions that differentiate one company's hardware from another.

With OpenFlow installed on routers and switches, researchers can use software on their computers to tap into flow tables and essentially control a network's layout and traffic flow with the click of a mouse. This software-based access allows computer scientists to inexpensively and easily test new switching and routing protocols. "Today, security, routing, and energy management are dictated by the box, and it's very hard to change," says McKeown. "That's why the infrastructure hasn't changed for 40 years."

Normally, when a data packet arrives at a switch, firmware checks the packet's destination and forwards it according to predefined rules over which network operators have no control. All packets going to the same place are routed along the same path and treated the same way.

On a network running OpenFlow, computer scientists can add to, subtract from, and otherwise meddle with these rules. This means that researchers could, say, give video priority over e-mail, reducing the annoying stops and starts that sometimes plague streaming video. They could set up rules for traffic coming from or going to a certain destination, allowing them to quarantine traffic from a computer suspected of harboring viruses.

And OpenFlow can be used to improve cellular networks as well. Mobile-service providers have begun to expand their networks using commodity hardware built for the Internet. But such hardware is horrible at maintaining connections when a user is moving: just think about the less-than-seamless way that a laptop's data connection is transferred from one wireless base station to another. OpenFlow, says McKeown, offers service providers a way to try out new solutions to the mobility problem.

McKeown's group receives funding and equipment from networking companies such as Cisco, Juniper, HP, and NEC, as well as cellular providers including T-Mobile, Ericsson, and NTT DoCoMo. Ideas tested on switches running OpenFlow could be incorporated into the firmware of new routers, or they could be added to old ones through firmware updates. McKeown expects that within the year, one or more of these companies will ship products with OpenFlow built in. –*Kate Greene*

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SUPERBROTHERS

A Zero-Emissions City in the Desert

OIL-RICH ABU DHABI IS BUILDING A GREEN METROPOLIS. SHOULD THE REST OF THE WORLD CARE?

By KEVIN BULLIS

The first hints of the project are visible. A white wall stretches through the desert, like a chalk line on a dusty playing field. A bus with darkened windows stirs a low cloud, ferrying workers past a cluster of steel cranes, two portable drilling rigs, and a stand of concrete columns sprouting rust-colored rebar. A tall wire fence guards rows of solar panels mounted on concrete pads.

The construction is the start of a vast experiment, an attempt to create the world's first car-free, zero-carbon-dioxide-emissions, zero-waste city. Due to be completed in 2016, the city is the centerpiece of the Masdar Initiative, a $15 billion investment by the government of Abu Dhabi, which is part of the United Arab Emirates. The new development, being built on the outskirts of Abu Dhabi city, will run almost entirely on energy from the sun and will use just 20 percent as much power as a conventional city of similar size. Garbage will be sorted and recycled or used for compost; sewage will be processed into fuel. Concrete columns will lift the city seven meters off the ground, creating space underneath for a network of automated electric transports that will replace cars. Planners predict that the development will attract 1,500 cleantech businesses, ranging from large international corporations to startups, and—eventually—some 50,000 residents.

The city will be an oasis of renewable energy in a country of five million, made rich by oil, that consumes the most natural resources per capita in the world. Seen one way, it's just the latest ostentatious project in a country that's been defined by them. Indeed, the UAE is already home to the world's tallest building and an enormous indoor ski facility that features a 200-meter-long black-diamond slope. Real-estate developers have dredged coral and sand from the sea floor, piling it up in the Persian Gulf to create islands in the shape of palm trees and a map of the world.

Yet many experts are optimistic that the city can become a test bed for new approaches to the engineering and architectural problems involved in creating environmentally sustainable cities. Although architects have already designed and builders constructed many small zero-emissions residences and commercial

DESERT CITY The Masdar City development, near Abu Dhabi, was in the first stages of construction last October. In the distance, cranes erect the first building, a research institute.

KEVIN BULLIS

buildings, projects involving large, multi-use commercial buildings have fallen short of expectations, using too much energy or failing to generate enough. Part of the problem is the growing complexity that comes with scale, says J. Michael McQuade, senior vice president of science and technology at United Technologies in Hartford, CT; today's design software hasn't been able to handle it. But Masdar City, itself developed with the help of extensive modeling, will be wired from the beginning to collect data that could prove valuable for developing better models. That information could make future zero-emissions cities cheaper and easier to build.

And the development is meant to make money, not just introduce new technology. "We want Masdar City to be profitable, not just a sunk cost," said Khaled Awad, the project's director of property development, at a huge real-estate exhibition in Dubai last fall. "If it is not profitable as a real-estate development, it is not sustainable." Yet if it is, it may be replicable.

"If environmental engineers, by gaining experience from building this wild city, become much more productive at building the next city, this starts to move from being science fiction to something Houston would adopt," says Matthew Kahn, a professor

ENERGY SURPLUS Masdar headquarters, shown above in an architectural rendering, is designed to generate more renewable electricity than it consumes; it would be the first large-scale, multi-use building to do so. Opposite: The building's structural cones, which support a roof laden with solar panels, will also provide light and ventilation. The pond helps cool the air.

©ADRIAN SMITH + GORDON GILL ARCHITECTURE

of economics at the University of California, Los Angeles. Gil Friend, CEO of Natural Logic, a sustainable-design company based in Berkeley, CA, agrees. "I see Masdar on the one hand as a playground for the rich," he says, "and on the other hand as an R&D opportunity to deploy and test out technology that, if things go well, will show up in other cities."

Of course, much of what's learned from Masdar won't apply outside the incredibly hot and sunny coast of the Persian Gulf. A site in Germany, which wouldn't get as much sunlight, couldn't rely as heavily on solar energy. A site in San Francisco might not need air conditioning, making information about advanced cooling systems less relevant. But if the project reaches its environmental goals, it will at the very least show that such cities can be built. "People say, 'Gee, that would be great. That would be a good idea, but obviously it's not possible,'" Friend says. "Once you can point at something, it takes away a lot of those arguments."

BREAKING GROUND

The Masdar Initiative is part of an ambitious plan to transform a resource-based economy—the third-largest exporter of oil in the world—into one based on knowledge and expertise. The name Masdar comes from the Arabic word for "source," and the plan is to make Abu Dhabi the Silicon Valley of alternative energy: a source of talent, patents, and startups in the very industry that could one day challenge the supremacy of oil. It's a daunting challenge to say the least, especially for a region that, according to Awad, "hasn't been known for innovation for a thousand years."

The city was conceived as a tax-free zone meant to attract clean-technology companies, largely from other countries. (The first tenant, General Electric, plans to build a 4,000-square-meter facility.) The Masdar Institute, the first part of the city to be built, is meant to be what Stanford University is to Silicon Valley. Developed in collaboration with MIT, which organized the curriculum and is helping to select and train the faculty, the institute will be a graduate research school, offering master's degrees and, eventually, PhDs. Its first class of 100 students will start courses this fall. And if graduates develop promising ideas and start companies, they can look to the Masdar Initiative for capital. Of the $15 billion the government has set aside so far for the initiative, only about $4 billion is designated as seed money for building the city's infrastructure. (The city is expected to cost a total of $22 billion, the rest to come from outside investors.) The remaining $11 billion is earmarked for a range of investments; projects so far include a solar-cell factory in Germany, an offshore wind farm in the United Kingdom, and efforts to reduce carbon emissions in Nigeria.

Still, the city is the most visible part of the initiative. It is by far the largest zero-emissions and zero-waste project in the world, according to several experts. (A larger "eco-city" development near Shanghai doesn't aspire to zero emissions.) Efforts elsewhere have

> "I don't know of any other project that has been as thorough in terms of its carbon monitoring. They're hunting down every molecule of carbon dioxide."

so far been limited to small to moderate-sized buildings and small communities, like a series of efficient row houses for 250 people in Wallington, South London. One of the most ambitious zero-emissions buildings to date, the Lewis Center at Oberlin College in Ohio, has 1,263 square meters of floor space. Masdar City will cover six square kilometers. Its headquarters alone, which will include offices as well as retail and cultural space, will occupy an 89,500-square-meter structure.

A detailed master plan for the city is complete, as are plans for the first buildings: the Masdar Institute and the headquarters. The city—which will include apartments and laboratories, but also factories, movie theaters, cafés, schools, fire stations, and so on—is intended to generate as much electricity as it uses. Its water will be recycled to save the energy costs of desalination. Vacuum tubes under the city will transport garbage to a central location, where it will be sorted, and as much as possible will be recycled. Trash that can't be recycled will be converted to energy through a gasification process and the leftovers incorporated into building materials. Sewage will be treated and some of it processed into a dry renewable fuel for generating electricity. The transportation system will include a light-rail line linking the development to downtown Abu Dhabi and the airport, as well as a personal rapid-transit (PRT) system with stations throughout the city. The PRT, a system of automated electric vehicles, will connect people to the rail line or deliver them to parking garages outside the city.

As is typical for zero-emissions projects to date, the city will need to rely in part on fossil fuels—both during construction and for power at night, when its solar panels won't be producing any electricity. The goal is actually best described as zero *net* carbon dioxide emissions: to reach the zero-emissions target, the developers will turn to a system of carbon credits. As the city is being built, a 10-megawatt array of solar panels will deliver power to nearby Abu Dhabi city, reducing demand for electricity from local natural-gas-fired power plants during the day. The carbon emissions saved will offset the emissions produced at night, when Masdar draws power from those same natural-gas plants. This solar array, and additional panels that will be installed as construction continues and electricity demand grows, will also offset the carbon emissions from construction equipment, from the processes used to make building materials such as concrete, and even from consultants' flights into Abu Dhabi from cities around the world.

So far, the developers have been accounting for "just about everything," says Pooran Desai, cofounder of BioRegional, a British company that helped develop the zero-emissions project in London and has consulted for Masdar. "I don't know of any other project that has been as thorough in terms of its carbon monitoring," says Desai. "They're hunting down every molecule of carbon dioxide."

THE MASTER PLAN

Dubai is a sprawling, car-dominated city about an hour's drive from Abu Dhabi city. Skyscrapers stretch along a 12-lane highway, Sheikh Zayed Road. Sunlight heats the unshaded areas to 46 °C in the summer. But there are a few places in Dubai where a person can walk outdoors in the middle of the day without risking heatstroke, and all are artifacts of the past. There are the covered souks, shaded marketplaces. And there is a historic district called the Bastakiya, which preserves some of the architecture that protected locals from the heat and humidity before the arrival of air conditioning. The houses and shops have thick walls made of dried coral and gypsum that absorb heat during the day, releasing it slowly at night. Because the buildings are packed closely together, they shade both each other and the narrow passages between them. The passages funnel breezes, cooling the buildings further.

When Gerard Evenden, a senior partner at the British firm Foster and Partners, began to make the master plan for Masdar City, he

SOLAR THERMAL COLLECTORS
Concentrated heat from the sun heats water to run a type of air conditioner called an absorption chiller. Thermal collectors lower electricity demand and cost less than photovoltaics.

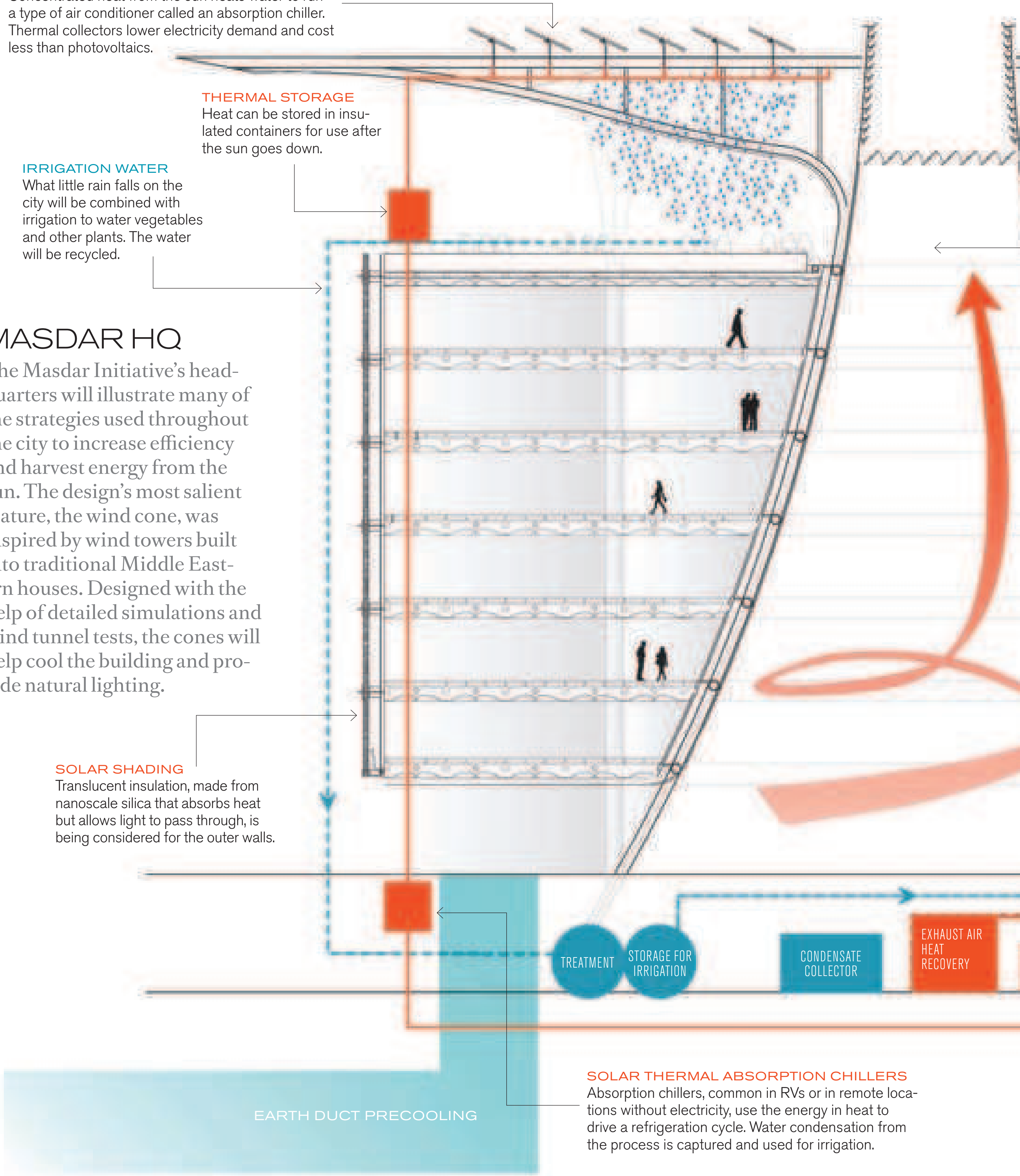
THERMAL STORAGE
Heat can be stored in insulated containers for use after the sun goes down.

IRRIGATION WATER
What little rain falls on the city will be combined with irrigation to water vegetables and other plants. The water will be recycled.

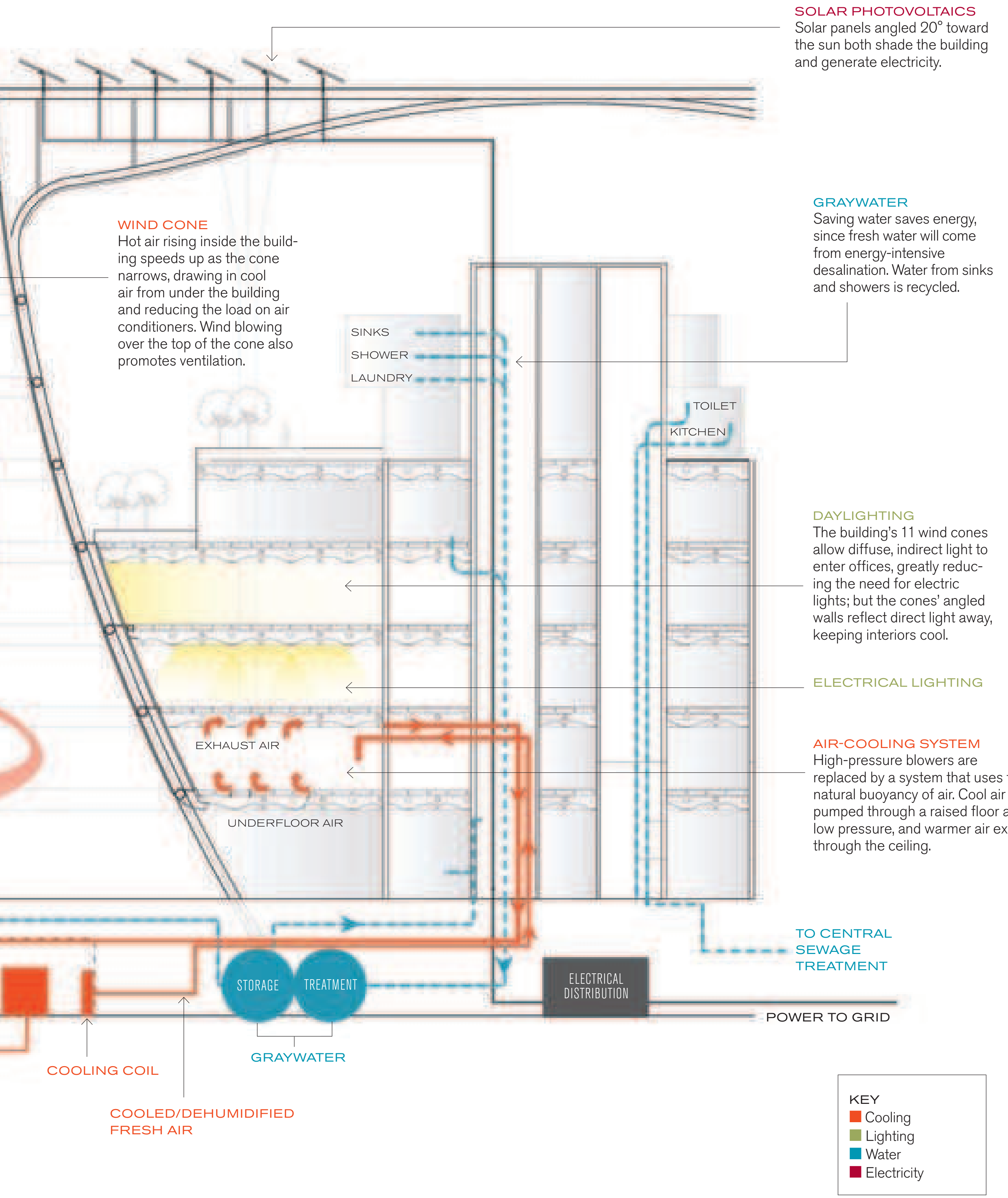
MASDAR HQ

The Masdar Initiative's headquarters will illustrate many of the strategies used throughout the city to increase efficiency and harvest energy from the sun. The design's most salient feature, the wind cone, was inspired by wind towers built into traditional Middle Eastern houses. Designed with the help of detailed simulations and wind tunnel tests, the cones will help cool the building and provide natural lighting.

SOLAR SHADING
Translucent insulation, made from nanoscale silica that absorbs heat but allows light to pass through, is being considered for the outer walls.



SOLAR THERMAL ABSORPTION CHILLERS
Absorption chillers, common in RVs or in remote locations without electricity, use the energy in heat to drive a refrigeration cycle. Water condensation from the process is captured and used for irrigation.


SOLAR PHOTOVOLTAICS
Solar panels angled 20° toward the sun both shade the building and generate electricity.
WIND CONE
Hot air rising inside the building speeds up as the cone narrows, drawing in cool air from under the building and reducing the load on air conditioners. Wind blowing over the top of the cone also promotes ventilation.
GRAYWATER
Saving water saves energy, since fresh water will come from energy-intensive desalination. Water from sinks and showers is recycled.
SINKS
SHOWER
LAUNDRY
TOILET
KITCHEN
DAYLIGHTING
The building's 11 wind cones allow diffuse, indirect light to enter offices, greatly reducing the need for electric lights; but the cones' angled walls reflect direct light away, keeping interiors cool.
ELECTRICAL LIGHTING
AIR-COOLING SYSTEM
High-pressure blowers are replaced by a system that uses the natural buoyancy of air. Cool air is pumped through a raised floor at low pressure, and warmer air exits through the ceiling.
EXHAUST AIR
UNDERFLOOR AIR
TO CENTRAL SEWAGE TREATMENT
STORAGE
TREATMENT
ELECTRICAL DISTRIBUTION
POWER TO GRID
GRAYWATER
COOLING COIL
COOLED/DEHUMIDIFIED FRESH AIR
KEY
Cooling
Lighting
Water
Electricity

looked to such traditional designs for ways to save energy. Since the city will depend almost entirely on electricity from solar power, which is five times the price of electricity from the local grid, the city needs to be roughly five times as energy efficient as competing developments nearby.

One of the first things Evenden did was subtract cars: with the highways gone, the city's buildings could be separated by passages just 7 to 12 meters wide, close enough to shade each other yet far enough apart to let in indirect light. That's a cheap way to reduce the need for not only air conditioning but electric lighting, the largest drain on electricity in commercial buildings. Insulation is cheap, too: in the Masdar Institute, Evenden plans to use 30-centimeter-thick insulation to keep out the heat. He's also incorporating "skins" of copper foil that reflect light and conduct heat away from the buildings. The foil will be protected from the desert dust by a self-cleaning Teflon-like plastic. To reduce the need for energy-intensive desalination, Evenden's design will cut water consumption by 75 percent through recycling, low-flow fixtures, and waterless urinals.

A small fraction of the energy that's still needed to run the city will come from waste-based fuel and perhaps geothermal power. The rest will come from the sun—but not all of it through expensive photovoltaics, which convert sunlight into electricity. Much cheaper devices that concentrate heat from the sun will heat water and run a type of air conditioner called an absorption chiller. (This is the same kind of technology that is used now in propane-powered refrigerators.)

In theory, it should all work. But in practice, even much less ambitious projects have failed. Oberlin College's Lewis Center features many of the same elements of energy-efficient design: thick insulation, natural ventilation with heat exchangers, plenty of windows to offset the need for electric lighting, and heat pumps rather than conventional furnaces. A 60-kilowatt array of solar panels on its roof was supposed to produce as much electricity over the course of a year as the building consumes. Yet the building initially used too much energy, and the solar panels were not adequate. To achieve zero net energy, the college had to install an extra solar array nearby, more than tripling the total power production. It added over a million dollars to an already expensive building, estimates John Scofield, a physics professor at Oberlin who has published a detailed analysis of the building's performance.

In general, architects find that predicting how energy-efficient systems will interact gets much harder as buildings get bigger. In buildings designed to take advantage of natural light, for example, designers can install sensors to automatically switch bulbs off when enough light comes in from outside. But lights turning on or off in one sensing zone may affect the sensors in another. In some buildings this has created a feedback loop that makes lights cycle on and off annoyingly.

Neighboring heating and cooling zones can also affect one another to create complex and unpredictable feedback loops, especially as the number of zones increases. United Technologies' J. Michael McQuade recalls what happened when his company designed what was supposed to be an intelligent heating, ventilation, and air-conditioning management system for a new building in Paris. The system was designed to coördinate 3,000 different zones. "When that building was first put together, it was a significant energy consumer, and it took a revamp of the integrated control systems to get it right," McQuade says.

If zero-emissions buildings are to be economical, Scofield says, the designs will have work from the start. "If you don't get it right," he says, pointing to the fiasco at Oberlin, "every correction you make is so much more costly than getting it right the first time."

PERSONAL TRANSIT

Masdar City will be raised on concrete stilts to make room for a personal rapid-transit (PRT) system that will replace buses and trains with smaller vehicles designed for four people. Masdar's planners expect the system to use less energy than conventional mass transit, and they say it will be more convenient, too.

In a PRT system, several small vehicles, often called pods, are kept waiting at each station. An individual or a small group boards one and selects a destination; the pod proceeds automatically to the destination without stopping. In a typical design, each vehicle resembles a battery-powered golf cart, only it's completely enclosed and somewhat bigger—and it lacks a steering wheel. The vehicle follows a track, which is connected to stations by on-ramps and off-ramps, and a computer controls how the pods enter and exit the stations: the ramps allow individual pods to make stops while others continue along the main track at top speeds. Simulations suggest that the systems could run with as little as half a second between vehicles.

But although PRTs look promising, they haven't caught on. That's in part because an early PRT-like system built in the 1970s in Morgantown, WV, gave the idea a bad name, says Jerry Schneider, an emeritus professor of urban planning and civil engineering at the University of Washington in Seattle and a longtime advocate of PRTs. "People would get on the vehicles and they wouldn't stop," Schneider says of the system, a transit line with automated cars for about 20 people. Technology has improved since then, he says, but there hasn't been a significant real-world demonstration of the updated systems.

Two demonstration programs are on the way. The first, which will transport passengers to a new terminal at Heathrow International Airport near London, will open later this year. Tests of that system are already under way. And the first stage of the system at Masdar City, to be built by the Dutch firm 2GetThere, is scheduled to be in place for the opening of the Masdar Institute this fall.

SHADY LANE Solar panels on the roofs provide sun protection in public spaces between buildings.

©ADRIAN SMITH + GORDON GILL ARCHITECTURE

THE TEST BED

Sameer Abu-Zaid isn't breaking a sweat. It's 39 °C with 74 percent humidity, but he says it's a nice day—much cooler than the summer in Abu Dhabi, when temperatures can reach 49 °C. Abu-Zaid, who's originally from Jordan and was most recently a manager at a semiconductor equipment manufacturer in Silicon Valley, will manage Masdar City's power and distribution infrastructure. "All of these modules have been tested at the factories," he says as he gives a tour of one of the first visible signs of the city, a test site where he's putting 41 arrays of solar panels from various manufacturers through their paces. "But they have been tested under standard test conditions: 1,000 watts per meter squared, 25 °C. Nice air-conditioned space. It is totally different here."

Dust from the desert quickly coats the panels, effectively dimming the light that reaches them. Abu-Zaid has learned that just four months of dust reduces the output of the solar arrays by more than 20 percent—information he'll use to decide how often to wash the panels, balancing power loss against water consumption.

Another problem is the heat. Solar panels' dark surfaces absorb sunlight, raising their temperature to as much as 80 °C. The heat affects some solar-cell technologies more than others. Some of the most efficient solar panels also produce less power when they get hot. Because of these trade-offs, it's not obvious which panels will work best at the Masdar site, Abu-Zaid says. At the test plot, sensors track how much various panels heat up, how effective different cooling strategies are, and how power output changes with temperature, among other factors.

Such data gathering will continue as the city grows. Its designers and engineers will measure both energy consumption and energy production. They will track water consumption down to the individual fixture. At Masdar headquarters, designers may use RFID tags in security badges to gather information on the way people use water and energy. Such measurements will allow designers and engineers to compare the real performance of the city with the performance predicted by laboratory tests and simulations.

REALITY CHECK

In the early 1960s, while the United States was rushing to put a man on the moon, electric fans and lights were still unheard-of in Abu Dhabi, according to Mohammed Al Fahim, a native of the emirate who has written a rare history of the place. That was not long after oil was discovered there, and well before the money started flowing. Al Fahim is from one of the wealthiest families in the area, yet both his sister and later his mother died because of a lack of basic health care. Now life expectancy in Abu Dhabi is virtually the same as in the United States. Before, the locals survived on water from brackish wells; now they drink fresh water from new desalination plants. The fragile and highly flammable palm-frond huts that housed most people have been replaced by gleaming glass-and-steel skyscrapers.

In many ways, the development of Abu Dhabi over the last few decades has reflected a frenetic effort to catch up with the developed world. Now, because of projects such as Masdar City, the emirate has a chance to race ahead. But in terms of urban development, it appears to be very much at a crossroads. In a few years, while the citizens of Masdar City will be pinching kilowatt-hours and using waterless urinals, go-carts will be screaming around a new track at a Ferrari theme park nearby, kids will be shrieking as they plummet down water slides at a new water park, and massive air conditioners will be roaring as they cool a new 700-store supermall. It's all part of a 2,500-hectare development that will dwarf the 640-hectare Masdar City.

The two developments are competing visions for the future of Abu Dhabi. If the Masdar project doesn't justify itself financially, it could indeed be just a green playground for the rich, an environmental theme park that is largely irrelevant for the development of sustainable technology on a broader scale. But if it is profitable, it could be a driving force for sustainable urban design. Then the oil-rich developers in the UAE and elsewhere might have a reason to build more green cities and skip constructing another ski slope in the desert. And developers worldwide will follow. TR

KEVIN BULLIS IS *TECHNOLOGY REVIEW*'S ENERGY EDITOR.

But Who's Counting?

NO ONE REALLY KNOWS HOW MANY PEOPLE VISIT WEBSITES. THAT'S A PROBLEM FOR THE FUTURE OF JOURNALISM, AND OF THE MEDIA IN GENERAL. BUT A SAN FRANCISCO STARTUP AND GOOGLE ARE BOTH WORKING ON SOLUTIONS.

By JASON PONTIN

In August 2006, when Roger McNamee invested in Forbes, he did so in part because its Web audience was thought to be huge. McNamee is a founder of Elevation Partners, a Silicon Valley private-equity firm that counts Bono of the rock band U2 as one of its managing partners; it specializes in big, bold investments in media and technology. Onstage at EmTech, Technology Review's annual conference, he said, "Look: I'm not investing in Forbes for its dead-trees business."

At the time, Jim Spanfeller, the chief executive of Forbes.com, claimed that more than 15 million readers around the globe had visited his site in February, making Forbes the world's leading business site. He supported his boast with research from ComScore Media Metrix, one of the two leading suppliers of third-party traffic data for the Web. The numbers seemed safe enough: Forbes.com's internal server logs showed even greater Web traffic. It was embarrassing, therefore, when ComScore announced that it had changed the methods it used to estimate worldwide audiences, and that little more than seven million people had visited Forbes.com in July. That placed Forbes's online audience below those of Dow Jones (whose sites include WSJ.com) and CNN Money (whose sites include Fortune). Bitchy press accounts suggested that McNamee had been overcharged—if not actually robbed—for his investment, which was variously reported at between $250 million and $300 million.

More than two years later, McNamee claims he always knew there were broad discrepancies between what the internal sever logs of Forbes.com showed and what third parties reported. "To be a headache, it would have to be surprising," he says. Instead, he suggests, he invested with no very precise idea of Forbes.com's audience: "I looked at every indicator that was out there. They were all bad. In the end, I had to think about it differently. I invested in Forbes because I thought the market was underserved, and because they had made fewer mistakes than anyone else." (To this day, McNamee declines to say how much he paid for how large an equity stake.)

People still can't agree on how many readers visit Forbes.com. "According to ComScore, we have six to seven million visitors [per month]; our own logs say 18 to 20 million," says Spanfeller. But while the difference between third-party and internal measurements is, for a variety of reasons, particularly striking in the case of Forbes, confusion about the size of online audiences is universal.

No one really knows how many people visit websites. No established third-party supplier of audience measurement data is trusted. Internal Web logs exaggerate audiences. This matters to more people than investors, like McNamee, who worry that they have no way to evaluate new-media businesses. The issues involved are technical, and occluded by ugly jargon, but they concern anyone anxious about the future of media as print and broadcast television and radio shrink in importance.

Happily, a California startup and Google are working to measure Web audiences in new and better ways.

THE PRICE OF JOURNALISM

Why care about something as arcane as dodgy audience measurement? Here's why: where content is free, as it is on most websites, the only thing that will pay for quality journalism—or, really, anything valuable at all—is advertising. For most new-media businesses, "display" or banner advertising is the main source of operating revenues. But the general inability to agree on audience numbers is stunting the growth of display advertising.

Every year, advertisers spend billions of dollars online; eMarketer, a research firm, predicts $25.7 billion in 2009 in the United States alone. Marketers study Web audiences to help them decide which sites to spend money on: they try to divine the number of people who visit a site every month, demographic details about those visitors, the length of time they stay on the site, the

Photograph by TOBY BURDITT

HE COUNTS Konrad Feldman, a cofounder of San Francisco–based startup Quantcast, sees big business in audience measurement.

number of pages they view, and the relationship, if any, between the ads they see and the way they behave. The people who actually buy ads—media buyers and planners at advertising agencies—use this information to choose appropriate sites for campaigns. Finally, publishers use the data to set advertising rates.

However, the correlation between the size of Web audiences and their value to advertisers is not direct. In print, the relationship between audience size and advertising spending is simple, because the prices of ads derive largely from a publisher's audited statement of circulation; media planners buy the total audience. Online, it's more complicated because the currency of display advertising is ad impressions, or the number of times a specific ad is served to a particular part of a website. "Audience numbers don't affect my buying decisions very much," explains David L. Smith, the chief executive and founder of Mediasmith, an interactive-media planning and buying agency whose clients include the National Geographic Channel and Sega. "If we were buying the total audience of a site, it would be different. But most of the time we buy packages of impressions."

Jim Spanfeller, who is a past chair and current board member of the Interactive Advertising Bureau (IAB), the industry association that represents sellers of online advertising, agrees with Smith that unreliable audience measurement doesn't directly affect ad spending, at least at larger sites: "If you're an established site like Forbes.com, you're selling on an ad-impression basis. The problem arises when an agency is thinking about moving money from one medium, like print or television, onto the Web." Then, Spanfeller says, media planners can't show their clients whether Web audiences replicate or complement the audiences that advertisers are reaching through traditional media. "We need believable numbers so that we can do cross-media comparisons," he says. Additionally, bad audience measurement "hurts smaller sites with more targeted audiences that don't have a lot of impressions"—the class of sites that Spanfeller, like many digerati, says occupies "the long tail."

Thus, the real consequence of the audience measurement problem is a chilling effect on the transfer of advertising from older media to new. Meanwhile, another form of online advertising is growing quickly—but it's not the ads publishers sell. The numbers clarify. Spending on "keyword" or search advertising (the sponsored links that appear near search results on Google.com and other search sites) grew 21 percent in 2008, mostly at the expense of print, local television and radio, and Yellow Pages advertising; it now constitutes 45 percent of all online advertising. That's because the effectiveness of keywords is unambiguous: advertisers pay directly for click-throughs or purchases. There's no need to appeal to anything so disputed as the size or composition of Web audiences. This growth in keyword advertising has mainly benefited the search firms. By comparison, the display advertising that media companies sell grew only 4 percent the same year.

For more than 100 years, advertising paid publishers and underwrote their production of great journalism; now, those ad monies are being funneled to search firms that create nothing but code.

Four percent growth might sound all right to some, but it occurs at the same time that advertising revenues in print are falling rapidly. For instance, ad spending in newspapers will decline from $50.8 billion in 2007 to $45 billion by 2012, according to Borrell Associates, a research firm. Even Forbes is sweating. As a private company, it does not disclose its revenues, but the number of ad pages in its magazine has been shrinking since 2000. At the same time, the company's online advertising revenues are reported to be between $55 million and $70 million, a figure Spanfeller did not dispute. That's not so much for a publication with an audience of 20 (or even seven!) million. In the glory days of print advertising, publications with much smaller audiences earned as much or more: *Red Herring*, which I once edited, earned more than $50 million in print advertising revenue in 2000, and its circulation was only 350,000 readers, according to Ted Gramkow, the magazine's former publisher.

Display advertising was meant to fund the great shift of readers to new media. It's not happening. For more than 100 years, advertising paid publishers and underwrote their production of great journalism; now, those ad monies are being funneled to search firms that create nothing but code. As Roger McNamee says: "Getting this right is absolutely necessary for publishers to be able to continue to do interesting things."

PANEL DISCUSSION

What's wrong with existing methods of measuring Web audiences? Lots.

ComScore and Nielsen Online, a division of the Nielsen Company, are the established leaders in the field of audience measurement and the sale, to advertisers, agencies, and publishers, of the data that audience measurement produces.

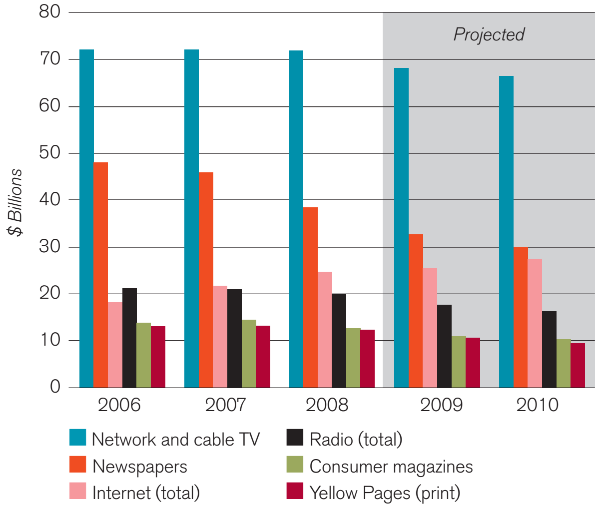
These third-party audience measurement firms exist because the internal logs of publishers are notoriously unreliable in quantifying user activity on a given site. "When publishers use their log files, there are many limitations," David Smith says. He says that the limitations of using these internal logs (a practice sometimes called "census measurement") include, in ascending order of impact, overcounting individuals with multiple computers or Web browsers; counting "mechanical visits" by Web "bots" and "spiders" (for example, when Google crawls the Web to estimate the popu-

ADDING IT UP

Although print, radio, and television still account for a large percentage of total advertising revenues, their share is decreasing as more and more ad dollars are spent online. But this isn't necessarily a boon to new-media publishers who rely on display advertising, because "keyword" or search advertising dominates the online ad market; it now accounts for nearly half of all online ad revenues.

U.S. ADVERTISING SPENDING

By selected media, 2006–2010



U.S. ONLINE AD SPENDING

By format, 2006–2010

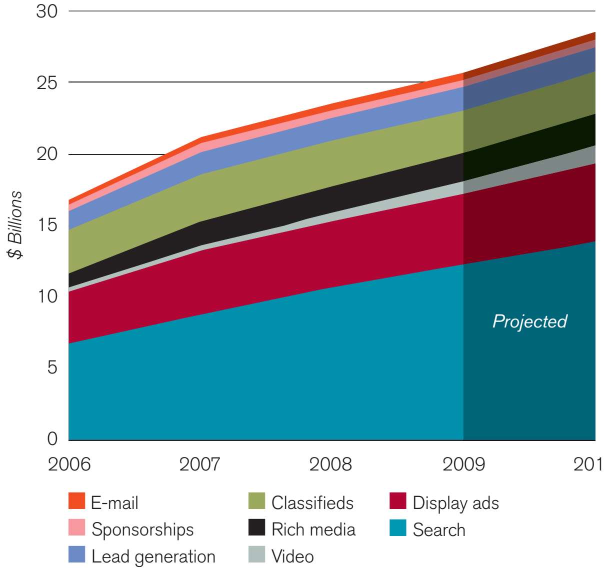


CHART SOURCES: JACK MYERS MEDIA BUSINESS REPORT; EMARKETER

larity of sites) as visits by real people; and overcounting individuals who periodically flush out the "cookies" of code that sites stash on browsers so that returning visitors can be recognized.

To create more-accurate audience numbers, ComScore and Nielsen Online rely on a methodology inherited from television audience research: the panel. Nielsen, for instance, has recruited nearly 30,000 panelists for its flagship product, called Netview. Panelists agree to have their Web browsing monitored through interviews and through "meters," or spyware, installed on their personal computers.

But what worked with television doesn't work nearly so well with the Web. "Panels are always problematical," says Spanfeller, "but on the Web they're super-problematical. Panels undercount by one-third to one-half." In short, publishers simply can't accept that their audiences are as small as panel-based measurements suggest they are.

Among the problems with panel-based audience research, according to both Spanfeller and Smith, is that it tends to undercount people who look at sites at work, because most companies' information technology managers won't install strange spyware on their computers. Sometimes, panelists lie to interviewers. Also, both say, there is a straightforward "sampling error" (what statisticians consider the misprisions that derive from sampling too small a portion of a general population): with as few as 30,000 panelists, the audiences of smaller sites are often grossly underestimated or missed entirely.

A final problem with panel-based measurements is that at the moment, neither Nielsen nor ComScore has itself been audited by an independent party. Who knows, both Spanfeller and Smith asked darkly, how valid the firms' reporting methods really are?

Nielsen defends its panels. "I guarantee you, if our numbers were higher than the publishers' server data, we wouldn't be having this argument," says Manish Bhatia, the president of global services at Nielsen Online. Bhatia notes that Nielsen does sell products, such as SiteCensus, that install software tags on publishers' websites and measure server logs. "In combination with panels, they're useful," he says. "But panels are more reliable, they provide demographic information, and they tell you what people do after they've seen an online ad."

For its part, ComScore also concedes that server logs have their place: they disclose which Web pages a publisher served, and when. But like Nielsen, the company insists that only panels provide an accurate measurement of audiences and their demographic makeup. "Servers don't measure people," says Andrew Lipsman, director of industry analysis at ComScore.

Why are Nielsen and ComScore so wedded to panels? According to David Smith, "The incumbents have a huge amount of money invested in their methodologies—and getting them to admit they have a problem isn't easy."

Roger McNamee is more blunt. "I understand why Nielsen is so bad," he says. "But why isn't there anything better? There's a huge market opportunity for any venture capitalist who is willing to fund a system that audits actual traffic."

"What we need is a third-party Omniture," says Spanfeller, referring to the website analytics software that many publishers (including Technology Review) use to log their own traffic.

MEASURE FOR MEASURE

Recently, I visited Quantcast, a San Francisco–based startup that is hoping to provide just such a service. Founded in 2005 and funded with $26 million, mainly from Polaris Ventures and Founders Fund, the company wants its service, which launched in 2006, to overthrow traditional panel-based Web audience measurement.

Konrad Feldman, the company's youthful, redheaded, British-born chief executive and cofounder, met me at the company's headquarters overlooking the Yerba Buena Gardens and the Moscone Center. In a large conference room with a cement floor, decorated according to the precepts of venture-capitalist high minimalism, he asked whether Technology Review was "quantified"—that is, whether its online visitors were tracked by the startup's software tags. After we confirmed that our site had been quantified for some time, he opened his laptop and searched for our URL at Quantcast.com.

An elegant dashboard of audience information was swiftly served: TechnologyReview.com, it said, had 342,000 "global people" and 205,000 "U.S. people." These numbers, which measured monthly visitors to our site, were not so low as those reported by traditional third-party audience measurement firms, but they seemed suspicious: throughout 2008, Omniture reported around 650,000 unique visitors to TechnologyReview.com every month. But we also learned that 32 percent of TechnologyReview.com's readers earned more than $100,000 a year and that 24 percent had postgraduate degrees, which seemed about right. (A peek at Forbes.com, which is not quantified but whose numbers the startup had extrapolated, showed that the business site had 4.9 million "U.S. people," who were richer than TechnologyReview.com's readers, although not as highly educated. Because Forbes was not quantified, Quantcast didn't supply Forbes.com's total worldwide audience.)

Quantcast's service, like that of existing audience measurement firms, begins with panels—or, more precisely, panel-like data in the form of "reference samples," provided to the company by third parties such as market research firms, Internet service providers, and toolbar companies, among other sources. These statistical methods create a basic model of U.S. Web traffic. But when publishers install Quantcast's tags on their servers, Quantcast gets more details; the startup adjusts for spiders and bots, people with multiple computers, and cookie flushers. The two methodologies are combined using something Quantcast calls its "mass inference algorithm," created with the aid of two Stanford University mathematicians and refined by the seven mathematically minded PhDs who work at the company. This algorithmic analysis of panel research and server-based measurement is unique in Web audience measurement (although Nielsen more coarsely combines the two methodologies with a service called VideoCensus, which tracks online video viewing). The resulting audience information, says Feldman, is much more reliable than anything offered by ComScore or Nielsen.

"Publishers and advertisers have used panel-based research for nearly 75 years," says Feldman. "So there's obviously an established way of doing things. But equally, there's a pretty clear recognition in the marketplace that something has got to change."

Because Quantcast's audience information is free (where ComScore's and Nielsen's measurements are not), the company hopes to make money by charging publishers who enroll in Media Planner, a service launched last May that helps media planners spend their clients' cash. Although Media Planner is wholly free for now, Quantcast wants to expand the service so that it can finely describe demographic subsets within websites' audiences, a utility for which the company believes the sites themselves will pay. Feldman explains this tricky idea: "You have a sales force at TechnologyReview.com, and they can't possibly speak to everyone who might value your audience. But if you can expose that audience to buyers, then you can create a way whereby buyers can discover the parts of your audience they find particularly valuable." Feldman says that Media Planner allows media buyers to find appropriate audiences, "but it's the publishers that should pay, as they're the ones getting higher rates for their audience segments." More ambitiously, Feldman hopes Quantcast's audience data, in combination with ad impressions, will create a new currency for advertisers, advertising agencies, and publishers that will make display ads more effective and therefore more valuable.

Feldman and his cofounder, Paul Sutter, the company's president, do not approach the problem of audience measurement as veterans of media. Feldman, a computer scientist, was the cofounder of Searchspace (now Fortent), which developed software to help financial-services firms detect money laundering and the financing of terrorists. Sutter founded the network optimization company Orbital Data (later acquired by Citrix) as an expert on high-performance computer architectures, a background that has proved useful as Quantcast processes the thousands of terabytes of data it has collected.

When the founders first conceived the company, Sutter says, "we just asked the most simple, kindergarten questions, and it soon became clear that the language that media buyers and planners were speaking was nothing like the language of Internet advertising, with its cost-per-clicks and so forth. Media planners liked to talk about audiences, demographics, and lifestyles. So the answer

> Quantcast claims that 85,000 broadly defined "publishers" have elected to be directly measured by it, including the Disney-ABC Television Group, NBC, CBS, MTV Networks, Fox, BusinessWeek, and SI.com.

was quantcasting, which means just reaching the people you want to reach." Today, the company claims that 85,000 broadly defined "publishers" have elected to be directly measured by Quantcast, including the Disney-ABC Television Group, NBC, CBS, MTV Networks, Fox, BusinessWeek, and Time's SI.com and CNNMoney.com.

Quantcast is not the only company with the bright idea of replacing panel-based audience measurement. Last June, Google announced a new service, Google Ad Planner, which uses the company's detailed knowledge of Web traffic to provide interested parties with a more accurate understanding of Web audiences. Wayne Lin, Ad Planner's product manager, demonstrated the service to me when I visited the GooglePlex in Mountain View, CA. Because Google owns DoubleClick, one of the two dominant systems for serving ads, Web audience data can be combined with the ad-serving system so that media planners know which sites are best suited for which ads. The combination should be powerfully attractive for media planners and marketers, says Lin.

How do media planners regard the two new audience measurement services? "We use Quantcast now at Mediasmith, but they are not complete enough yet to be a total solution," says David Smith, who briefly advised the startup during its formation. The difficulty, according to Smith, is that the site's audience information won't be really useful—let alone a new currency—until more publishers elect to be quantified. Jim Spanfeller agrees. "They're to be commended for working hard on the problem," he says. "But it's very much a chicken-and-egg thing."

As for Google's Ad Planner, Smith says, "the agencies will never stand for it." Smith, like everyone I spoke to, argued that media planners will resist Google's audience information because no one wants one company to be so dominant in online advertising: were Ad Planner to be widely adopted, Google would be selling keywords through its search advertising network, AdWords; selling banner advertising through its display advertising network, AdSense; serving those ads through DoubleClick; and advising media planners on where to spend their advertising dollars.

Ad Planner also lacks a number of important features that an advertising agency might expect from an audience measurement service. According to Smith, it offers neither very detailed demographics nor a full explanation of its methodologies. Patrick Viera, TechnologyReview.com's own digital strategist and West Coast advertising manager, said disdainfully when I asked his opinion: "Yeah, I looked at it. It doesn't do anything you want. It's just a tool for selling AdSense."

Still, says Smith, there's demand for something new. "Publishers have to use third-party measurements, but third parties [such as ComScore and Nielsen] may underestimate audiences, and the truth is probably somewhere in between. That's why new companies like Quantcast have a chance."

GROWING PAINS

But neither Quantcast nor Google nor improved products from ComScore and Nielsen Online could, by themselves or in combination, fix display advertising and thereby ensure the future health of media.

Whatever audience measurement tools are adopted, they will themselves have to be validated by an independent party. Quantcast, ComScore, and Nielsen Online (but not Google) are all in the process of being audited by the Media Rating Council (MRC), which was established by the U.S. Congress in the 1960s to audit and accredit the ratings of broadcasters. Accreditation will smooth disputes about the different audience measurement methodologies, according to George Ivie, the chief executive of the MRC: "It will help bring the numbers closer together; and it will explain and make transparent the differences between the census and panel systems."

In addition to the disagreements about the size of Web audiences, though, online advertising suffers from deep structural problems that must be addressed before media planners and their advertising clients will spend really large sums. These are various and dauntingly technical, but according to David Smith, they all involve, in one way or another, the absence of commonly accepted, automated means to create, sell, serve, and track the performance of online ads.

Fixing all that will take years, as will the adoption of undisputed audience measurement methods. "This industry is only 13 years old," says Smith. "It grew rapidly with few standards for six years. Then it collapsed, with very little research and development for four years, and has just been getting back to the right kind of R&D and standards in the past three."

Still, by any estimate, the general confusion about Web audiences is the reason why the online medium has matured in so ungainly a fashion. "It's an amazing topic," wrote Roger McNamee in a conversation using the messaging service of the social network Facebook. "You could see it coming a mile away. Unfortunately, the remedy is not yet obvious." TR

JASON PONTIN IS THE EDITOR IN CHIEF AND PUBLISHER OF *TECHNOLOGY REVIEW*.

ESSAY

The Family Business

MODERN PHYSICS THROUGH THE GENERATIONS

By GINO SEGRÈ

In September 1955, just off the boat from Italy and not yet 17, I enrolled as a freshman at Harvard College. Luckily, I already knew English. Although I was born in Florence just before the outbreak of World War II, my family had taken refuge in New York during the conflict, not returning to my birthplace until 1947. Eight years later, when it was time for me to go to college, my parents decided I should do so in the United States. My trip to Cambridge began with their delivering me to Florence's Santa Maria Novella train station and waving good-bye. The Ferrovie dello Stato, Italy's train system, conveyed me to a boat at Le Havre, which in turn transported me to New York. Another train landed me in Boston. With a bulging suitcase in hand, I took the subway from South Station to Harvard Square.

I still remember my dismay when, expecting to be greeted by the inviting setting I had seen in pictures, I exited from underground to see nothing but traffic and busy stores. I timidly asked an elderly, professorial-looking passerby the whereabouts of Harvard. He answered, "You must be a freshman. Walk a few steps forward, turn to your right, and you will see a gate. Go through it!" The sight of the promised Harvard Yard reassured me. A room on the quad also portended well. But soon I received another shock, albeit a minor one: wearing a tie and jacket was obligatory at all meals. I came equipped with the latter, but I had no tie. Since this meant no meals, I immediately went out and bought a bow tie—the clip-on variety, so that I wouldn't have to learn how to tie the knot.

During my first year of college I dutifully wrote home once a week, reporting on the progress I was making but glossing over some of my adjustment difficulties. In time I made close friends, many of whom were struggling with the same problems. My immediate academic goal was to learn physics, the discipline I had chosen. This didn't turn out to be as easy as buying a bow tie: I was not the genius I had hoped to be. Nonetheless, after four years of serious endeavor, I was accepted by good graduate schools and chose to go to MIT. That choice was due largely to Francis Low, a physics professor from *down the river* who came to deliver an endowed set of lectures at Harvard during my senior year. Even though I didn't understand much of what he was espousing, Harvard's graduate students and faculty paid close attention to the equations he was writing on the blackboard and the intriguing Chew-Low scattering model he was presenting. It all sounded exciting; I checked with my faculty advisor, who agreed that going to MIT seemed like a good idea. Having little mechanical aptitude, I also decided that I would try to become a theoretical physicist.

In November 1959, my first year in graduate school, I heard that Owen Chamberlain and my uncle Emilio, an experimental physicist, had won that year's Nobel Prize in physics for their discovery of the antiproton. The existence of antimatter particles—identical to the electron and the proton in mass but opposite in electric charge—had been proposed almost 30 years earlier by Paul Dirac as a result of an attempt to combine quantum mechanics with the special theory of relativity in a single beautiful equation. Most physicists initially regarded this idea as wildly speculative, but the 1932 discovery of the antielectron (a.k.a. the positron) proved that Dirac was right. Finding antiprotons took another quarter-century because their production in the laboratory required powerful particle accelerators, which were not available until the 1950s. Unlike the discovery of the antielectron, which had come as a shock and a surprise, proof of the antiproton was expected. But it was a crucial confirmation of the equations that theoretical physicists were now using as common tools.

Back in 1959, I wondered if my uncle's Nobel Prize was an augur that I was making the right choice. I thought that if he could succeed in the profession, perhaps I would as well. On the other hand, my uncle was also setting the bar incredibly

BETTMANN/CORBIS

THE UNSEEN, SEEN
Uncle Emilio, Clyde Wiegand, and Owen Chamberlain view evidence of the antiproton, the discovery that earned Emilio and Chamberlain the Nobel Prize.

high. My father tried to cheer me up by writing that, prize or no prize, it was better to be a theoretical physicist than an experimental one like my uncle. His reasons for reaching this conclusion were murky at best; he was a professor of ancient history and knew next to nothing about the nitty-gritty of physics. I couldn't help thinking that his judgment might have more to do with the unfortunately strained relations between the two brothers than with anything else.

In any case, my chosen field—high-energy physics, sometimes called elementary-particle physics—seemed particularly promising, and I was happy with the choice. The interplay between theory and experiment was especially exhilarating. Experimentalists were finding surprising results, with theorists providing explanations shortly afterward; in other cases, theorists made predictions that were quickly proved or disproved by ingenious experiments. The most striking example at the time was Tsung-Dao Lee and Chen Ning Yang's analysis of how a reaction and its mirror image might be distinguished from one another, a violation of so-called parity symmetry. Their 1956 conjecture was rapidly confirmed, and the Nobel Prize was awarded to them just a year later, in 1957.

In addition, ever-larger accelerators were being put into operation, producing new and often unexpected particles at a prodigious rate. Murray Gell-Mann was pioneering attempts to group these new entities into families, with members related to one another by symmetry considerations. And he was only 30, the same age Lee had been when he received the Nobel Prize. This was a new field with new leaders. I was beginning to think that the situation might be like the earlier development of quantum mechanics, when Wolfgang Pauli, Werner Heisenberg, and Dirac had created a revolution while still in their mid-20s. Since I was only 21, there was hope that I could be a player within a few years if I had the necessary ability.

Fifty years later, I view that moment differently. I see myself not stepping into a rapidly emerging field but entering at the midpoint of a great century-long arc that stretches from Ernest Rutherford's first scattering experiments to CERN's Large Hadron Collider—from a seemingly unimportant research exercise carried out by two students to an international endeavor engaging thousands in a decade-long quest to build a multibillion-dollar machine. Though the beginning was simple, the end point is probably the most technologically sophisticated experiment ever attempted.

I called this century-long search an arc, but an ascent might be a more appropriate metaphor, for we have moved steadily over the course of these hundred years toward bigger and bigger experiments. On the other hand, we have also been descending, probing matter at ever smaller scales—from the atom to the nucleus to the protons and neutrons to the quarks

A REMARKABLE TEAM Marie Curie and her daughter Irène worked together as nurses during World War I. Later they would work together as physicists.

POPPERFOTO/GETTY IMAGES

and, finally, to whatever comes next. I place my entry into the field not only at a chronological midpoint but also at an organizational one—a time when a single university group could still mount a successful experiment, when computers were in their infancy and analyses could be carried out in days.

Perhaps one should actually start the story 113 years ago, when Henri Becquerel discovered radiation coming from uranium ores; this indicated the presence of a novel energy source, more powerful than anything then known. Two years later, Marie Curie and her husband, Pierre, published their discovery that radioactivity was an atomic property of uranium and other materials. It was not long before Rutherford, a young New Zealander working in Cambridge, England, found that this radiation had two components; he called them alpha rays and beta rays. But I place the beginning of the arc in 1909, when two young physicists working for Rutherford, by then an established professor in Manchester, began at his urging a new

kind of experiment. They bombarded a thin gold foil with alpha particles, constituents of alpha rays like the ones Rutherford had discovered a decade earlier. Since that revolutionary experiment, physicists have been smashing ever-more-energetic particles against ever-more-sophisticated targets. The means have changed over the course of the century, but the goal of probing the constituents of matter at smaller scales has not.

It was in 1911 that Rutherford realized what the Manchester experiments implied: the atom, contrary to prevailing beliefs, was composed of electrons moving about a minuscule, massive core. The following year he used the term *nucleus* to describe that core. Measuring typically little more than a hundred-thousandth of the atom's radius, the nucleus nevertheless contained essentially all of its mass.

Twenty years later, probing deeper, physicists discovered that the nucleus is composed of neutrons and protons, presumably held together by a previously unimagined force. Forty years after that, they found that neutrons and protons are in turn each made up of three quarks. This year, when the Large Hadron Collider begins operation in full, we will take the next step on the journey—one whose progression Abraham Pais, a physicist and historian, has described in a book aptly called *Inward Bound.*

PHYSICS' FIRST FAMILIES

Over the span of this century-long arc, the energy of the projectiles employed has increased by a factor of a million, the cost of the necessary apparatus from a few hundred to billions of dollars, and the size of the teams at work on a typical experiment from at most two or three to hundreds. But this story is much more than simply one of bigger machines and larger expenditures. It is also a tale of the people who achieved this extraordinary growth—people who were linked to one another, sometimes by blood or marriage (as I can attest, having a slew of relatives in what I sometimes jokingly refer to as "the family business"), but in all cases by common aims.

I had a romanticized image of the field when I entered it 50 years ago, but it's been moderated by finding out about some of the bitter disputes that have arisen along the way. (Two of my early heroes, Lee and Yang, once as close as brothers, have not spoken to each other for decades.) Yet while I now see the warts, I also have a greater appreciation for the support and even affection so common in the physics community. Great labs such as the Cavendish at Cambridge, Curie's Radium Institute, and Niels Bohr's Institute for Theoretical Physics often fostered quasi-familial feelings, occasionally heightened by the sight of parent and child working side by side.

A family-like atmosphere certainly existed wherever Rutherford presided. At the end of World War I, he left Manchester. Joseph John Thomson, who had received a Nobel Prize in 1906 for discovering the electron, decided to step down from Cambridge's Cavendish Professorship, a post he had held for 35 years. Rutherford, then at the peak of his powers, was his natural replacement. He accepted, and for the next 15 years the Cavendish Lab, under his leadership, was the world's premier research facility in nuclear physics.

At the Cavendish, Rutherford was jovial but stern when he needed to be, always encouraging the group he called "his boys." Bohr once wrote of him, "However modest the result might be, an approving word from him was the greatest encouragement for which any of us could wish." There was no doubt who was the "father" and who had the last word, but Rutherford's intuition was formidable and his judgment excellent, and he was never threatened by suggestions from others. He began his day by going over the physics news with the assistant head of the lab, James Chadwick, who had worked by Rutherford's side since his own undergraduate years at Manchester before World War I. Rutherford would then walk around the lab, offering suggestions. When preliminary results were available, he would sit on a stool near the experimenter's lab bench, pull a pencil out of his waistcoat, and check to see if the data seemed right. The lab's restrictions now seem archaic: doors that shut punctually at 6:00 P.M., mandatory vacations, and a prevailing ethos that you built your own equipment—not too expensively, either. Viewed through today's lenses, Rutherford's behavior was paternalistic. But there was no resentment.

No experiment at the Cavendish would be more influential than Chadwick's 1932 discovery of the neutron. Ushering in the modern era of nuclear physics, it was a triumph for Rutherford's boys, and it marked the start of a period in which experimentalists regained the lead from theorists like Bohr, Heisenberg, and Schrödinger, who had been dominant since Rutherford discovered the nucleus 20 years earlier.

The nucleus's makeup had been a puzzle ever since that surprising discovery. It was known that an oxygen atom, for example, had eight electrons surrounding a nucleus containing eight protons, but the atom's mass seemed to indicate the presence of 16 protons—twice the expected number. It was commonly believed that nuclei contained additional protons tightly bound to the very much lighter electrons, thus neutralizing their charges. But this didn't seem to make much sense: how was it possible that electrons were sometimes inside the nucleus, if ordinarily they resided well outside it? An alternative explanation, long suspected by Chadwick and Rutherford, was the existence of a particle with a mass very close to the proton's but with no electric charge. As expected on the basis of mass estimates, the oxygen nucleus contained eight of these newly named neutrons, alongside the eight protons.

Chadwick's discovery beat out the cross-Channel competition of Madame Curie's daughter Irène, who had formed a formidable research duo with her husband, Frédéric Joliot. Irène and Frédéric had the Nobel Prize in physics within their grasp twice, having achieved first sightings of both the positron (the electron's antiparticle) and the neutron. Each time, they misidentified their observation and saw the prize go to others. Forging ahead despite these disappointments, in January 1934 the Joliot-Curies announced the first instance of artificially induced radioactivity, a result that would have immense repercussions for medicine as well as pure science. All were satisfied when, in 1935, Chadwick received the Nobel in physics and the chemistry prize went to the young French couple.

The literal family ties hardly end with the Curies. William Lawrence Bragg, Rutherford's successor as Cavendish Professor, had shared the 1915 Nobel Prize in physics with his father, William Henry Bragg, for their study of crystal structure by means of x-rays. Rutherford's predecessor, too, saw his son receive a Nobel, albeit 31 years after his own: curiously, Joseph John Thomson was cited for discovering that the electron is a particle, while George Paget Thomson received the award for proving that the electron is a wave. Cognoscenti recognize this apparent contradiction as a confirmation of one of the central tenets of quantum mechanics: that an electron (as well as a photon) is both a particle and a wave, though the two manifestations cannot be detected simultaneously. The particle nature of radiation explains the photoelectric effect; the wave nature of electrons has enabled the development of the short-wavelength microscopes that bear their name.

The man principally responsible for developing the theory of wave-particle duality is Niels Bohr, a theoretical physicist whose career was critically shaped by a 1912 stay with Rutherford in Manchester. A deep bond of affection was forged between the established scientist and the young Dane, who later referred to Rutherford as a second father and even named one of his sons Ernest. Although Rutherford tried more than once to have Bohr join his professional family, first in Manchester and later in Cambridge, Bohr's commitment to his native Denmark could not be broken. Yet the two maintained a tie grounded in their common physics interests and their complementary areas of expertise. In approaching problems of first the atom and later the nucleus, Rutherford looked to Bohr for guidance in theoretical matters and Bohr to Rutherford for the significance of experiments (though as their frequent correspondence attests, neither shied away from criticizing the other's conclusions).

In Copenhagen, Bohr modeled his style of work on Rutherford's, tailoring it to the pursuit of theoretical problems. As in Cambridge, the ideal was to surround yourself with young people and follow their work at an almost daily level while pursuing your own. To that end, Bohr founded the Institute for Theoretical Physics in 1921. Carrying the notion of family even further than Rutherford's lab, it was housed in a single three-story building comprising a lecture hall, a library, work space for the young physicists, a cafeteria, and an apartment on the top floor for Niels and Margrethe Bohr and their children. One of the children who grew up there, Aage Bohr, succeeded his father as director of the Institute for Theoretical Physics and, in 1975, won a physics Nobel of his own.

Out of this institution came the Copenhagen interpretation of quantum mechanics, the set of rules for what is probably the 20th century's greatest physical-science revolution.

UNCLE EMILIO HEADS TO BERKELEY

While all this was going on, my father, Angelo, was establishing himself as a professor of ancient history. He had heard about the great advances in physics, chiefly while spending three years away from Italy in the early 1920s, one in Vienna and two in Munich. Though he didn't fully comprehend the physicists' achievements, he sensed the excitement surrounding the discoveries and felt, with some regret, that the future belonged with them. Despite his quite respectable career as a historian, I believe there was nothing he admired more than science, and physics in particular.

By primogeniture my father was destined to take over running the paper mill his father owned in Tivoli, a beautiful, ancient city close to Rome. But from an early age he showed no aptitude or inclination for the task. Fortunately, his slightly younger brother, Marco, had both, so my father was free to do something else. Since Italian Jews saw academics as a clear path for advancement, it is not surprising that my father's other brother—my uncle Emilio—became a professor, too. I sometimes think that these two brothers, one born in 1891 and the other in 1905, belonged to two different generations: one never learned to drive a car, and the other was the first in his group of friends to have one. However, I also see how much alike they were, and I realize that despite their differences, each maintained a lively interest in the other's work.

I suspect that my father felt at some level that he had failed twice, first by not running his father's paper mill and second by not becoming a scientist. But perhaps he thought that he could recoup some of his losses by having his children become physicists. And they both did. I don't know what message he gave my brother, but when I was a teenager he pointed me toward that future in no uncertain terms. According to him, theoretical physics was the best possible profession, because "you will be able to tell right from and wrong, and you will not have to talk to anybody you don't want to speak to." I am not so sure he

was correct on either count, but I did follow his directive and do not regret it. I am, however, getting ahead of myself.

Though my father was already a physics fan, news from his brother in the late 1920s had clinched his admiration for the subject. Emilio had entered the University of Rome as an engineering student and probably would have continued on this path had his life not changed in early 1927, as he was turning 22. A fellow student, the son of a mathematician, told Emilio that a supposed genius named Enrico Fermi had just been selected, at only 26 (an unheard-of age for a Rome appointment), for a new chair of theoretical physics. Furthermore, since there apparently were no Rome students interested in physics, he was looking for recruits. My uncle and his good friend Edoardo Amaldi, later the leader of post–World War II Italian physics, were the first to respond to the call.

When I was a teenager my father pointed me toward my future in no uncertain terms. According to him, theoretical physics was the best possible profession, because "you will be able to tell right from wrong, and you will not have to talk to anybody you don't want to speak to."

The ensuing exploits of the growing Rome group were remarkable in absolute terms but even more important for Italy, which felt, correctly, that it was lagging behind its northern neighbors in scientific research. Italians are still proud of the group's achievements, and even today, Fermi is regarded as the only true physics genius the country produced in the 20th century. He is also arguably the only 20th-century physicist from any country to have achieved true greatness as both a theorist and an experimentalist.

Fermi's early fame rested on his achievements as a theorist, and perhaps most famously on his explanation of a longstanding mystery: nuclear decays involving the emission of an electron. This phenomenon seemed to violate the bedrock physics principle of conservation of energy. Furthermore, how was it possible that an electron could be emitted from within the nucleus when there presumably were none there to begin with? In late 1933, Fermi was on a skiing vacation with a few members of his group. He convened them in his hotel room and, as my uncle remembers, told them he had solved the problem. This was probably the most important piece of work he had yet done, he said, and might well be the most significant he would ever do. Drawing on an idea of Wolfgang Pauli's, he proceeded to explain his insight, showing them how a new kind of interaction would allow a neutron to decay into a proton, an electron, and a very light particle—not yet observed—that had no electric charge. The last two would escape from the nucleus simultaneously, with the neutral particle carrying away the seemingly missing energy. To distinguish the new particle from the massive neutron (*neutrone* in Italian), he gave it the name *neutrino*.

Fermi's most notable work as an experimentalist also began around late 1933, when he realized that the recently discovered neutron provided the means for a new kind of projectile in Rutherford-type experiments. Protons or alpha particles, used heretofore, had to have relatively high energies to penetrate a nucleus, since the electrically charged target and projectile repelled each other. A neutron, on the other hand—even a slow one—could freely make its way into a nucleus, because it was without electric charge. Fermi, his old friend Franco Rasetti, and a few assistants—including, of course, Amaldi and my uncle—quickly began a multiyear study of such reactions, yielding many new and important discoveries about how nuclei behave.

The enterprise came to an end when Italy adopted racial laws in 1938. Fermi, realizing that his family was endangered (his wife, Laura, was Jewish), left for the United States in December of 1938—departing from Stockholm, where he had just received a Nobel Prize in recognition of his pioneering work with neutron scattering. His group at the University of Rome dissolved.

As Fermi was leaving Italy, two German chemists, Otto Hahn and Fritz Strassmann, found a curious result when they bombarded uranium with neutrons. Lise Meitner, a longtime collaborator of Hahn's who had been forced to flee Germany a few months earlier because she was Jewish, helped explain what would prove to be a crucial discovery. During a walk on Christmas Eve of that year, she and her physicist nephew Otto Frisch (family again) realized that uranium nuclei had probably been split into two pieces as they absorbed a neutron, a process that would necessarily lead to a large release of energy. Two weeks later, Frisch coined the term *nuclear fission*

to describe what had happened in the Hahn-Strassmann experiment. It also became clear that if additional neutrons were released during fission, a chain reaction could occur. The first controlled such event, guided by Fermi, took place in a squash court at the University of Chicago in December 1942. Soon after that, Fermi and many others, including my uncle, moved to Los Alamos to work on developing a much bigger chain reaction: the atom bomb.

My family left Italy soon after the Fermis did—in our case, supposedly to visit the 1939 World's Fair in New York. I was then only seven months old. My seven-year-old brother might benefit from the experience, the U.S. consul in Florence politely suggested when we applied for visas, but wasn't I a little young? My father replied that Jewish children were now becoming interested in such events at a very early age. Fortunately, the consul—knowing full well our intention of staying in the United States if at all possible—had a sense of humor and an abundant dose of charity.

Emilio left Italy in the summer of 1938. His exodus took him to Berkeley, CA, a place he had visited in the summer two years earlier. He was gratefully discovering that the physics family was growing rapidly across the Atlantic and welcoming refugees from Europe. Ernest Lawrence's Radiation Laboratory at Berkeley was in the process of replacing Cambridge's Cavendish as the world's great nuclear-physics lab. In some ways Lawrence was just as much a pioneer as Rutherford. One grew up in New Zealand as the child of immigrants and attended local Canterbury College. The other, a grandchild of immigrants, was raised in South Dakota and studied at his state university. Both were forceful and effective leaders in later life, but their aims and styles were different. Rutherford liked inexpensive experiments that could fit on a bench. Lawrence, an enthusiastic fund-raiser and entrepreneur, was interested in building bigger and better cyclotrons, machines capable of accelerating particles to much higher energies than anything that could be achieved at Rutherford's laboratory. In realizing his dream, Lawrence made ample use of America's ingenuity and its new economic power.

Rutherford believed in building the apparatus that the physics required. But Lawrence's philosophy was different: build machines, he thought, and the physics would follow. This was a decisive point in the arc of 20th-century physics. It would no longer be possible for a few individuals to simply set out and collect the necessary tools for an experiment they planned. The era of big physics had begun.

Chadwick had discovered the neutron in February 1932. Two months later John Cockroft and Ernest Walton, encouraged by Rutherford and by George Gamow, a protégé of Bohr's, managed to induce nuclear disintegration by bombarding lithium nuclei with accelerated protons. This would be the old Cavendish Lab's last Nobel Prize–winning physics experiment. Within months, Lawrence had replicated their result with his cyclotron and then quickly moved on. By 1939, the year he was awarded the Nobel for his achievements in developing that apparatus, Lawrence was planning the fourth and largest version—one with a 184-inch chamber and a magnet weighing thousands of tons. Its eventual successor, the Bevatron, began running in 1954. The name came from its ability to accelerate particles at energies up to billions of electron volts, a thousand times greater than those achieved by the first cyclotron. The discovery of the antiproton a year later, thanks to the high-energy collisions the Bevatron made possible, was its first dramatic success (and the reason for Uncle Emilio's Nobel).

Yet Berkeley's physics heyday would soon be over, just as the Cavendish's had passed. Probing the structure of neutrons and protons would require beams of higher energy, and this meant even bigger and more expensive particle accelerators. Since it was becoming increasingly clear that no single institution could afford to construct or staff the new machines, consortiums had already begun forming to plan for building them. A group of universities in the eastern United States joined forces in 1947 to construct an accelerator on Long Island. The result was Brookhaven National Laboratory's Cosmotron, which started running in 1952. Europe's major nations made their own plans, loath to be left behind although World War II had left them impoverished. They banded together in 1954 to found CERN, the European Organization for Nuclear Research (the acronym comes from the French *Conseil Européen pour la Recherche Nucléaire*), in Geneva, Switzerland. Its first particle accelerator began operation in 1957.

PACKING MY BAGS FOR SWITZERLAND

These advances were very much on my mind as I decided where to use the two-year postdoctoral fellowship I had been awarded by the National Science Foundation after completing my PhD thesis in 1963. CERN seemed to be the natural choice. A stay there would allow me to see more of my parents and, in some way, to reconnect with the Europe I had left behind. I made the decision without hesitation, even though CERN, having yet to make any major discoveries, seemed to suffer from an inferiority complex vis-à-vis its rivals in the United States. Spirits were nevertheless high there, as I found on arrival. In addition, the laboratory's director general, Victor Weisskopf, was an inspiring presence, familiar to me because he had been a professor at MIT. Weisskopf, who came to CERN in 1961, appeared to represent a melding of the great old European tradition and the new American can-do attitude.

BODIES IN MOTION Enrico Fermi and Niels Bohr stroll along Rome's Appian Way discussing, perhaps, the mysteries of the nucleus.

PHOTOGRAPH BY SAMUEL GOUDSMIT, COURTESY AIP EMILIO SEGRE VISUAL ARCHIVES, GOUDSMIT COLLECTION

Though only in his mid-50s, Weisskopf had worked with the likes of Bohr and Pauli during the heyday of quantum mechanics and the beginnings of nuclear physics. After arriving as an immigrant to the United States from Europe in his late 20s, he had been an active participant on the atom bomb project and had later helped develop MIT as a center for physics teaching and research. He now seemed to be the right person to guide CERN in its transition to world eminence. Weisskopf also tried to re-create, in a completely different and much larger setting, some of the atmosphere he had benefited from in Copenhagen 25 years earlier. Writing of Bohr in his autobiography, he says, "From the beginning he made the most profound impression on me. He was my intellectual father." And Weisskopf tried to convey some of this same sense of family to the young CERN scientists—speaking informally about physics on Monday afternoons, inviting us to his Geneva house, and always emphasizing what a wonderful enterprise we were engaged in, how lucky we were to be able to work on the great and beautiful problems of physics.

CERN's climb to success was not easy, nor was the United States standing still. With a 1968 ground-breaking for the National Accelerator Laboratory (now renamed Fermilab), U.S. physicists were planning a machine capable of accelerating protons to almost 10 times the energy reached at Brookhaven, a level competitive with anything Europe would achieve. But CERN persevered, and within a decade of my arrival, it announced its first truly major discovery. There is an old adage in physics that "yesterday's discoveries are today's tools and tomorrow's background events." In 1933 physicists were quite sure they would never be able to detect a neutrino being scattered by another particle. By 1973 CERN had a neutrino beam that made it possible to study the details of a newly identified force that acted on these particles and on electrons and protons. This was a breakthrough. It would be another decade before CERN would announce its triumphal sighting of the particle that mediated this force, commonly called the Z boson. Its discovery was another example of the back-and-forth between theory and experiment that has characterized the whole century-long arc. Theorists had predicted that the Z boson would be 90 times as massive as a proton; consequently, it would not be directly observed until machines were capable of reaching the energies necessary for its production. When the Z turned up in 1983, with the predicted mass, the discovery became one of the cornerstones in the establishment of what has come to be called the standard model of particle physics. The long journey begun in 1909 had now reached a summit. The atom's constituents and the nature of all the forces between them finally seemed to have been identified.

By then I had long since left CERN. In the summer of 1965 I began a two-year postdoctoral appointment at Berkeley, still a power in the world of high-energy physics, even if its impact was not quite what it had once been. A side benefit of this stay in California was getting to know my uncle Emilio, now a senior professor at the university. I had seen very little of him while growing up because my father and he always seemed to be at odds. Emilio, never known as an easy person to get along with, described their relationship this way in his autobiography: "My patience and tolerance derived in part from a certain regard I felt for Angelo's keen intellect, and in part because in several respects I felt that I to some extent resembled him." My own view was that, despite Emilio's claims of patience and tolerance with my father, neither of them was

a paragon of such virtues. However, spending time with my uncle, now near retirement, was a great window into the evolution of 20th-century physics and, with no sibling rivalry in play, an altogether pleasurable family experience.

My father was a historian who wanted to be a scientist. I now saw Emilio turning to history, in part to examine the scientific events he had witnessed and in part to describe the extraordinary people he had met and sometimes worked with. Within several years he had written *From X-Rays to Quarks,* an engrossing history of a hundred years of physics as observed by a participant. I read the book (in its original Italian version) when it appeared in 1976, but I was too involved with the day-to-day events of establishing my own career to give it much thought. By then a professor at the University of Pennsylvania and deeply involved in the mysteries of the standard model, I was back at CERN for a year on a Guggenheim fellowship. Europeans were now beginning to talk about building a new kind of particle accelerator: one that would produce very high-energy electron-positron collisions, envisioned as ideal for studying Z meson decay. The Z had of course not yet been observed experimentally, but its discovery was anticipated on theoretical grounds, and planning had to start right away, since it took many years to construct a large accelerator. This was now the way high-energy physics operated: build for the expected and the unexpected. The LEP (Large Electron-Positron Collider) was formally approved in 1981. Construction began in 1983 and finished in a little over five years; by the end of the 1980s, the LEP, also known as the Z Factory, was working marvelously.

MY FAMILY Uncle Emilio (right) and my future brother-in-law Victor Weisskopf discuss the CERN accelerator's progress.

The United States now needed to act if it wished to remain competitive. In 1993, Congress canceled the U.S. physics community's response, the Superconducting Super Collider, after a $2 billion initial expenditure. With that move, it was clear that the balance of power was shifting to Europe. Thirty years earlier, I had returned to a Europe envious of America's success in building particle accelerators. It was now America's turn to be envious. The completion of the Large Hadron Collider has simply underlined this shift, though I do wish to emphasize that the collider's European location does not mean the end of U.S. participation in operating such machines. In an era of global scientific coöperation, one finds people from all countries involved in ensuring the success of experiments at the great accelerators. In fact, the field has rightly claimed to be a model of international collaboration.

The completion of the Large Hadron Collider and the hundredth anniversary of Rutherford's first scattering experiments make this seem like a good time to reflect on the century of incredible changes in this field—where the arc has taken us, where we want to go, and what new challenges loom ahead.

Newton's aphorism "If I have seen a little further, it is by standing on the shoulders of giants" is as true for today's physicists as it was for him. The generation of Einstein, Planck, Curie, Rutherford, and Bohr, our intellectual ancestors, laid the foundations for understanding the atom. Then came the early 20th century's young geniuses, who discovered quantum mechanics, explored the nucleus, and built the new machines. Though the divisions blur, a new generation—my own—emerged in the wake of World War II. We identified the elementary particles and the forces between them, uniting them in the standard model.

This has been a remarkable journey, but great challenges remain. How do the elementary particles acquire mass? Is there some deeper theory explaining the identities of particles and the relations between forces that also encompasses Einstein's grand vision of gravity? Many think that string theory is a giant step in this direction, but conclusive evidence is not yet available. These are all questions for the present generation, now reaching its peak of creativity.

Nor can one omit from the story the realization that conditions fleetingly created by collisions in the highest-energy accelerators mimic those that took place, for a fraction of a microsecond, immediately after the Big Bang that marked the

AIP EMILIO SEGRE VISUAL ARCHIVES

universe's beginning. Because of this development, which has caused a great stir, elementary-particle physics and cosmology now frequently see their aims as parallel. Today's young physicist might go to a conference called "Inner Space/Outer Space" or study a book called *From Quarks to the Cosmos*.

This convergence has also led to a revival of interest in neutrinos, for they seem to play an important role in our cosmos. They are a subject that has become near and dear to me. We now speak routinely of situations that Fermi, my uncle, and their friends could not have imagined in the winter of 1933. Experiments have shown neutrinos being emitted from the sun's core. We even know that in the explosion following a large star's collapse, neutrinos carry off 99 percent of the emitted energy in a single 10-second burst. This amount is comparable to all the energy radiated by the sun in its 10-billion-year lifetime. Yet three-quarters of a century after the neutrino's existence was proposed, we still don't know its mass. It is much, much less than that of the electron, but how large is it?

I conclude by bringing you up to date on my end of the family business. None of Emilio's children became physicists, but one of his grandsons and a nephew of mine did. My three daughters didn't go into the business, but the oldest married the son of a well-known theoretical physicist. So perhaps a grandchild will carry on the tradition, though I am not sure how much influence the two grandfathers have. The days when parents told their children what careers to pursue are over.

Given all this history, it will probably not surprise you that I married the daughter of a physicist, Herman Hoerlin. I know that when my wife, Bettina, told him about me, he checked me out in *American Men and Women of Science* before giving his approval. Fortunately, I passed. Finally, I acquired a physicist brother-in-law a little over 15 years ago, when Bettina's sister Duscha met, fell in love with, and soon married an elderly Austrian widower. He was none other than Viki Weisskopf, the idol of my youth at MIT and CERN. At first I was a bit tongue-tied in his presence, but then I realized that it was going to be okay. He was *family*.

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REVIEWS

DATA MINING

Personalized Campaigning

VASTLY FATTENED VOTER DATABASES WILL PROVE TO BE AMONG THE 2008 PRESIDENTIAL RACE'S MOST ENDURING LEGACIES.

By DAVID TALBOT

If you're a Democrat (although Republicans will have similar experiences), don't be surprised if a canvasser knocks on your door in 2012 and, glancing at his iPhone, says, "Ms. Smith, thanks for your $50 donation four years ago—and for attending the Joneses' party on the environment. Care to call voters in Ohio to help reëlect President Obama? Oh, and your neighbor Mrs. Jensen couldn't get to the polls in 2008. Think you could give her a lift on Election Day?"

As you answer his questions, the canvasser will stroke his iPhone, and a campaign server will squirrel away your answers. Minutes later, you'll get an e-mail from the campaign: "Thanks, Ms. Smith, for promising to make calls in Ohio." If you click the link, up will pop a list of 10 Ohio voters whose answers to phone-bank callers in 2008 suggest that they wavered between McCain and Obama and were concerned about the environment. You might call them and—following a provided script—explain Obama's environmental record, ask for their views on several issues and candidates, and record their answers with mouse clicks on a Web interface.

The next day, one of the Ohioans you'd spoken to—the one who professed strong support for Obama and a willingness to volunteer—will receive an e-mail with the names and addresses of 10 unregistered but voting-age people within a half-mile who, according to a party algorithm that analyzes demographic and consumer data, are likely Democrats. She'll hit the streets, armed with Ohio voter registration forms she's downloaded from a link in the e-mail. Another Ohioan—who'd told you he worked as a nurse and strongly supports Obama—will get a different e-mail. It will contain a list of licensed nurses in swing states, and a script for calling them to enlist their support.

DEMOCRATIC NATIONAL COMMITTEE VOTER DATABASE
www.votebuilder.com

CATALIST DATABASE
www.catalist.us

OBAMA FOR AMERICA E-MAIL LIST
www.barackobama.com

On it will go. The night before Election Day, your phone will ring; an Obama volunteer somewhere will have logged in to the campaign's website to make get-out-the-vote calls. "Just wanted to remind you to vote," she will say, following a script based on the latest data about you, "and to check in with Mrs. Jensen to see if she needs that ride."

The next morning, when you drive Mrs. Jensen to the firehouse, you will notice a college student standing near the sign-in desk, quietly tapping her BlackBerry. She is a poll watcher. She will note your arrival and—with a stroke of her finger—erase your name and Mrs. Jensen's, in real time, from the Democrats' Election Day call list.

VIRAL VOLUNTEERING

This is a plausible scene from the next presidential election, which will be an unprecedentedly personal campaign. In 2007 and 2008, the vaunted Obama Web operation produced a powerful by-product: hundreds of millions of new pieces of data on voters. That information is now held principally by the Obama campaign, the Democratic National Committee, and a private database company called Catalist.

Both Democrats and Republicans have long maintained databases with whatever intelligence they can muster on individual voters. Party officials obtain lists of registered voters (about 170 million people) from the secretaries of state in the 50 states, plus the names of those who are eligible to vote but aren't registered (another 50 million people). Then they use phone banks and shoe-leather canvassing to learn which candidates these citizens prefer and what issues they care about. Other sources provide new details: who has been a campaign donor or volunteer; who shows up in public databases of people holding, say, nursing licenses or hunting licenses. During the last election cycle, the Web tools for accessing and adding to these databases got better, and far more volunteers used them. "We went from a bolt-action rifle to a machine gun, but we also trained lots of people how to use it," says a senior Democratic Party insider.

The Republicans are no slouches, either. Five years ago, the big story was their push toward microtargeting—identifying niche

MARTIN O'NEILL

groups on the basis of hobbies, group membership, and even consumer data purchased from commercial vendors. "If somebody gets *Field and Stream*, they're much more likely to be a Republican voter than a Democratic voter," Matthew Dowd, a Bush-Cheney 2004 strategist, observed in a 2006 interview with *Frontline*. "If somebody gets *Mother Jones*, they're much more likely to be a Democratic voter." Democrats had fallen behind in the quest to target voters, partly because each state party kept its own data.

But that changed in 2007, when DNC chairman Howard Dean centralized data collection and management. Dean hired Voter Activation Network, a company based in Somerville, MA, to combine data from the 50 states and create an Internet interface for the resulting database, VoteBuilder. Any Democratic candidate anywhere in the nation could log in, download customized lists, and contact voters. Any detail gleaned from these voter contacts was fed back into the database for the benefit of all future Democratic candidates.

Then came Barack Obama, whose Web campaign operation turbocharged the collection of data on individual voters *(see "How Obama Really Did It," September/October 2008 and at technologyreview.com)*. In early 2007, Obama's campaign established a social-networking site called my.barackobama.com, or MyBO; it included a custom interface for VoteBuilder. This allowed any Web volunteer visiting the Obama site to obtain lists of voters from the DNC database. Volunteers phoned these voters, asked questions about their politics, and recorded their answers through the MyBO interface, pumping more data into the DNC's servers. (Three million such calls were made in just the final four days of the campaign.) The senior Democratic source says it's safe to say that at least some information was recorded about the opinions of 200 million Americans. Thanks to Obama's Web operation and those of other Democratic candidates, the DNC's database is now 10 times the size it was in 2004, according to Voter Activation Network founder Mark Sullivan. At the same time, Obama built an e-mail list of 13 million, supplemented with information about the activities of these supporters within MyBO. Beyond the formidable Obama and DNC databases, a third database serves Democrats and progressive organizations. Built by Catalist, a company headed by Bill Clinton's former deputy chief of staff Harold Ickes, it started with the national voter list and added supporter data from progressive groups like the Sierra Club.

INFORMED SURROGATES

With these three databases, notes Vijay Ravindran, who until recently was Catalist's chief technology officer, "the Democratic side has a lot of information that it could bring to bear. It has enriched the slate of volunteers who can be 'turned on' for future grassroots activities. It has information on people's positions that can be used to lobby congressmen." Thomas Gensemer, managing partner of Blue State Digital, which built the Obama Web tools, says the databases will probably be used to mobilize Obama voters in support of the president's agenda. "Think back to 1992, when President Clinton put through health-care reform [and it failed]," he says. "If you'd had a list of demonstrated activists, online or off, who could help fight back, that is a powerful use for an informed surrogate."

While it remains to be seen whether President Obama will try to deploy his supporters in that way, it's clear that the databases are useful instruments. The Obama campaign tried many interesting strategies in 2008. Its "neighbor to neighbor" tool, for example, let volunteers plug in their addresses and pull up the names of 25 neighbors to call; veterans were recruited to call other veterans in swing states. But such strategies are now possible in unprecedented variety, and at an unprece-

dented scale. "You are getting potentially all the way to a one-to-one message," Ravindran says. "In terms of how things move in the future, that is the Holy Grail."

What's a bonanza for campaigning also has its potentially intrusive side, of course. "The availability of huge amounts of personal information is new, and we don't agree as a culture on what's useful and [what] we're in favor of, and what's plain creepy," says David Weinberger, an Internet advisor to the 2004 Howard Dean campaign, who's now a fellow at the Berkman Center for Internet and Society at Harvard. "It's exactly the same question that marketers are facing, but this is in the sphere of citizenship, and it's important to get this right. There isn't an obvious path forward yet."

Indeed, political campaigns know much more about you than they used to. They always knew whether you voted, because this is public information. Now they know the details of your campaign activities and responses to campaign messages, right down to which e-mail messages led you to click open a link. They can trace any social networks you constructed inside a campaign site. When they buy consumer databases, they know even more about you.

Somehow, under President Obama, all this seems fairly benign—at least to his legions of well-wishers. To them, the idea that his DNC or his campaign might use knowledge of someone's environmentalism to help fight for tougher clean-air laws will appear laudable. The idea that distributed volunteers might dilute some of the power of big donors and pressure groups in the next campaign will seem to many like a step in the right direction. But in another context, such activities might take on another color altogether—just as another kind of huge gathering on the Washington Mall might seem more ominous than uplifting. Information has always been power. National leaders of all kinds have always wanted both. TR

DAVID TALBOT IS *TECHNOLOGY REVIEW*'S CHIEF CORRESPONDENT.

DNA

A Hole in the Genome

A SMALL CHUNK OF DNA LINKED TO SCHIZOPHRENIA, MENTAL RETARDATION, AND AUTISM MAY CHANGE THE WAY WE THINK ABOUT DISEASE.

By EMILY SINGER

Go about 145,000,000 bases (or "letters") down the long arm of chromosome 1 and you'll come to 1q21.1, the genetic address of a small but important piece of DNA that is particularly prone to mistakes. When chromosome 1 is duplicated during normal cell division (say, in creating sperm or eggs), short, repetitive bits of DNA within this stretch are all too likely to mistakenly pair up, raising the chances that the new cells will have extra or missing copies of specific pieces of DNA.

1Q21.1

Those small mistakes can have a big impact on people who carry them. Several studies in the last year have found that missing or extra pieces of DNA in the 1q21.1 region put the bearer at risk for a surprisingly broad range of psychiatric and neurological disorders, including autism, schizophrenia, and mental retardation. The discovery that one piece of DNA can lead to such diverse outcomes is opening new avenues in the study of disease. Rather than focusing solely on finding a common genetic flaw in everyone with a particular disease, researchers have begun to examine the various consequences that the same genetic flaw may have in different people. These studies suggest that even patients with different diagnoses may share common biological problems. "It's been eye-opening," says Mark Daly, a geneticist at the Broad Institute in Cambridge, MA, "because it's made us realize that in searching for the molecular basis of disease, it may be profitable to search for connections between seemingly unrelated phenotypes." Last year, Daly and his colleagues identified a section of DNA on chromosome 16 that also raises the risk of several different brain disorders, suggesting that this pattern may be common in the genetics of disease.

Physicians have long known that structural abnormalities in our genomes—deletions, duplications, and rearrangements of large stretches of DNA—trigger develop-

mental problems and disease. Down syndrome, for example, results from an extra copy of chromosome 21. But over the last few years, new kinds of microarrays—small slides dotted with specific sequences of DNA—have begun allowing scientists to efficiently search the genome for architectural flaws too small to be visible with a microscope. These errors, called copy number variations, are distinct from the single-letter changes that until recently have been the focus of most research into genetic variation. Ranging in size from one thousand to more than one million base pairs, they can encompass part of a gene or one or more entire genes.

The far end of region 1q21.1, which at about one million bases long constitutes a tiny percentage of the roughly 3.2 billion pairs of letters that make up human DNA, harbors just one of the genome's many "hot spots"—so called for their tendency toward structural instability. But in this region, structural abnormalities—especially missing sequences—seem particularly troublesome. Intrigued by this mysterious morsel of DNA, Heather Mefford, a pediatric geneticist at the University of Washington in Seattle, compiled data on variations in 1q21.1 from clinical genetics labs around the world. She found that 25 patients in a sample of more than 5,000 people with autism, mental retardation, or other congenital abnormalities were missing the same chunk within the region. While that is a small percentage, no one in a similar-sized group of healthy people carried that particular mistake, meaning that the deletion is the likely cause—or at least partial cause—of the patients' problems. Studies by other researchers have linked similar changes in the region to schizophrenia, as well as to abnormal head size and accompanying developmental delays.

Different studies linking 1q21.1 to mental retardation, autism, and schizophrenia all identified deletions or duplications in approximately the same region. That's because this particular stretch is flanked by repetitive sequences prone to rearrangement. It contains at least eight known genes, the functions of which are mostly unknown. "This region of the genome must clearly have one or more genes that are important for normal cognitive development," says Mefford, whose research was published in the *New England Journal of Medicine* in October.

Scientists hope that identifying the underlying mechanisms affected by the missing or duplicated piece of DNA will provide new targets for drug development. But at this point, it's not clear whether it's one gene or several that raise the risk of disease, or how deletions and duplications of the same piece of DNA can trigger outcomes as different as schizophrenia and mental retardation.

The findings do hint that autism, schizophrenia, and mental retardation have common biological underpinnings, a conclusion that has some precedent. Children with mental retardation often have psychiatric and behavioral problems as well, although these may be undiagnosed or underappreciated in the face of their cognitive deficits. And some families may have a history of mental illness, but not of a specific illness.

Mental retardation, autism, and (to some extent) schizophrenia are developmental diseases, diagnosed in childhood or adolescence. So identifying a common biological flaw may shed light on the crucial components of neural development and suggest ways to help when that development goes awry. Perhaps a disruption in the 1q21.1 region of the chromosome inherited from one parent can send some fundamental developmental process off course. The ultimate impact might depend on environmental factors, variations in other parts of the genome, or the version of the gene inherited from the other parent. Someone whose genome has mistakes in other regions that are important for brain development and cognitive function might end up with mental retardation. Someone whose genome is largely intact, but who has a mutation in a gene linked to autism, may end up with high-functioning autism.

A better understanding of the molecular consequences of errors in 1q21.1 and other recently identified hot spots may help redefine autism and schizophrenia and even change the way they are diagnosed. Both disorders cause a wide range of symptoms, and they are currently identified through behavioral and cognitive tests. Physicians may now be able to augment that diagnosis with the results of genetic testing. Only a small percentage of people with autism or schizophrenia will carry a particular genetic variation. But researchers hope that as more copy number variations are linked to these disorders, such genetic characterizations will become useful tools for predicting the best treatment for a given patient.

"At one time in the history of medicine, when you had a cough and an infection of the lungs, they called it pneumonia," says James Lupski, a physician and scientist at Baylor College of Medicine. Now we know that pneumonia is actually a group of different diseases, both bacterial and viral, that must each be treated differently. Eventually, someone developed a way to distinguish bacterial pneumonia from other forms, Lupski says, and that set the stage for the development of different treatments.

A diagnostic test that can detect copy number variations already exists: array CGH, the same test scientists use in research studies. It is currently used in clinical genetics labs to diagnose unexplained cases of mental retardation, developmental delay, and, increasingly, autism as well. It's not yet clear how to use the results to guide treatment—especially in disorders such as autism, for which no drugs are available to treat the root cause. But when it comes to other disorders, scientists are optimistic. "We have lots of effective psychiatric drugs, but it often takes weeks to find the right one," says Lupski. "Could this simple characterization predict the one that works best? That alone would be of tremendous benefit to patients." TR

EMILY SINGER IS *TECHNOLOGY REVIEW*'S SENIOR EDITOR FOR BIOMEDICINE.

PERSONAL COMPUTING

Our Own Devices

WHY WE LOVE THE MACHINES WE SHOULDN'T.

By EMILY GOULD

A little less than a month ago, I bought a new MacBook. I'm sure it's superior to my five-year-old G4 in hundreds of ways that I will never know or care enough to appreciate, but so far I've only managed to notice that it's ... *not the same*. Typing is more slippery—there's none of that reassuring vestigial typewriterish resistance behind the barely raised letters and numbers. Both shift keys are intact, the screen isn't smeary, and the whole apparatus isn't encrusted with crumbs and cat hair. There's a built-in camera so I can (entertain the horrifying prospect of engaging in) video chat with friends and loved ones. No one has yet photographed this computer to illustrate a magazine story about, like, "Bloggers: What's Up with That?" When I use it to access the Internet, there are no effortful whirring sounds, no spinning wheels, no hesitations. I never have to force-quit half the programs I have open in order to make one of the others work. Really, it should be no problem at all—really, I should be *eager*—to transfer my music and documents and programs to my new computer so I can get the old one out of my life forever.

EVOCATIVE OBJECTS: THINGS WE THINK WITH
Edited by Sherry Turkle
MIT Press, 2007, $24.95

THE INNER HISTORY OF DEVICES
Edited by Sherry Turkle
MIT Press, 2008, $24.95

MACBOOK PRO (2008)
15-inch: 2.4 gigahertz

POWERBOOK G4 (2003)
15-inch: 1.67 gigahertz

So why is my old computer still sitting on my bedside table (or, okay, more likely tucked into the covers at the foot of my bed), ready for the ritualistic little online tour of duty that—it pains me to admit—I compulsively make every day, first thing in the morning upon waking and last thing before sleeping? It's a yellowed husk of its pristine-white former self, tragically hefty-looking next to its slimmer, silver younger sibling. Sure, we've been together through good times and bad—and the bad times were bad in a specifically computer-centric way. So much of my life had been spent looking at and touching that machine, and then so much of my life had been spent recording what had happened by looking at and touching that machine. The concrete evidence of those experiences can easily be exported to my new machine. After that happens, what remains will bear as little resemblance to the object my fingers have spent the past few years caressing daily as a corpse bears to the living body it used to be. But even once its little mechanical soul has been reincarnated, the physical shell of my old laptop will remain a reminder of all the good things, and all the bad things, I used it to do.

My morbid attachment to my old machine confuses and shocks me, but it probably wouldn't surprise MIT's Sherry Turkle, who as a clinical psychologist and a professor of the social studies of science and technology has spent several decades studying and writing about the way mechanical objects construct and complete the self.

In two recent books, *Evocative Objects: Things We Think With* and *The Inner History of Devices*, Turkle has invited ethnographers, children, psychiatrists, and a great many "ordinary" people—a disproportionate number of whom seem to be academics—to contribute essays about the most important objects in their and their patients', students', and research subjects' lives, and all the feelings and memories these objects evoke. The essays run the gamut from very analytical to very diaristic. A lot of them are just not very good: the academics, especially, often write about personal things as if they're composing a college admission essay, and few of the other contributors seem to have understood that there are formal conventions of personal writing beyond "this happened, then that happened."

But then there are moments that make the reader realize how valuable Turkle's project is. In *Devices*, for example, we learn that some video-poker addicts wear double-layered pants so they don't have to get up to urinate. They are sometimes surprised to find, after hours of play, that they've soiled or vomited on themselves—that's how immersed they are in the microdecisions that the game requires. And they all use the same language of transport and transformation to describe their relationship with the machine that lulls them into this disembodied trance. "My body was there, outside the machine, but at the same time I was inside the machine, in the king and queen turning over, almost hypnotized into *being* that machine." "You're over there in the machine, like you're walking around inside it, going around in the cards." This is where anyone who has ever found it hard to get up from the computer—which by now must be everyone—cringes.

Though Turkle refrains, in her introductions and conclusions, from handing down judgments on biomechanical relationships, she includes many essays that revisit this theme of cyborgish machine-reliance. This is where the books become most intimate and most interesting. I had never before understood the creepy, visceral mechanics of dialysis, or the constant low-level worry implicit in the daily life of a diabetic, but in chapters about dialysis machines and glucometers, these details—small, precise, harrowing—shone in a way they wouldn't have in any other context. A women's or general-interest magazine might publish a triumphalist narrative about "My Battle with Diabetes," but by exploring, plain fact by plain fact, his daily intimacy with a glu-

cometer, Joseph Cevetello writes meaningfully about his disease without moralizing. His glucometer is both savior and scold, and he both treasures its utility and resents his dependence on it. Ultimately it's just an inescapable part of his life, simultaneously as incidental and as rich with selfness as a whorl of freckles or a scar.

I am not the first, of course, to endow a computer with power beyond its technical utility. In *Objects*, tech writer Annalee Newitz writes about how her early experiences with the Internet were colored by romance, with the result that even now, "computers make me think of love." This was one of the only essays in these collections that I felt was a retread: "On the Fringes of the Physical World," Meghan Daum's tragicomic, marvelously egoless account of her disappointment when an intense virtual love affair failed to translate into meatspace, covered the same territory without coming to such neat conclusions about the "community" and the "sharing" that Newitz says infuse computer nerds' dreams of unselfish, reciprocally beneficial, perfect love. But there were aspects of the laptop essay that spoke to my own love, born of intense familiarity, for my old computer's physicality. "I would recognize the feel of its keyboard under my fingers in a darkened room," Newitz writes. Check.

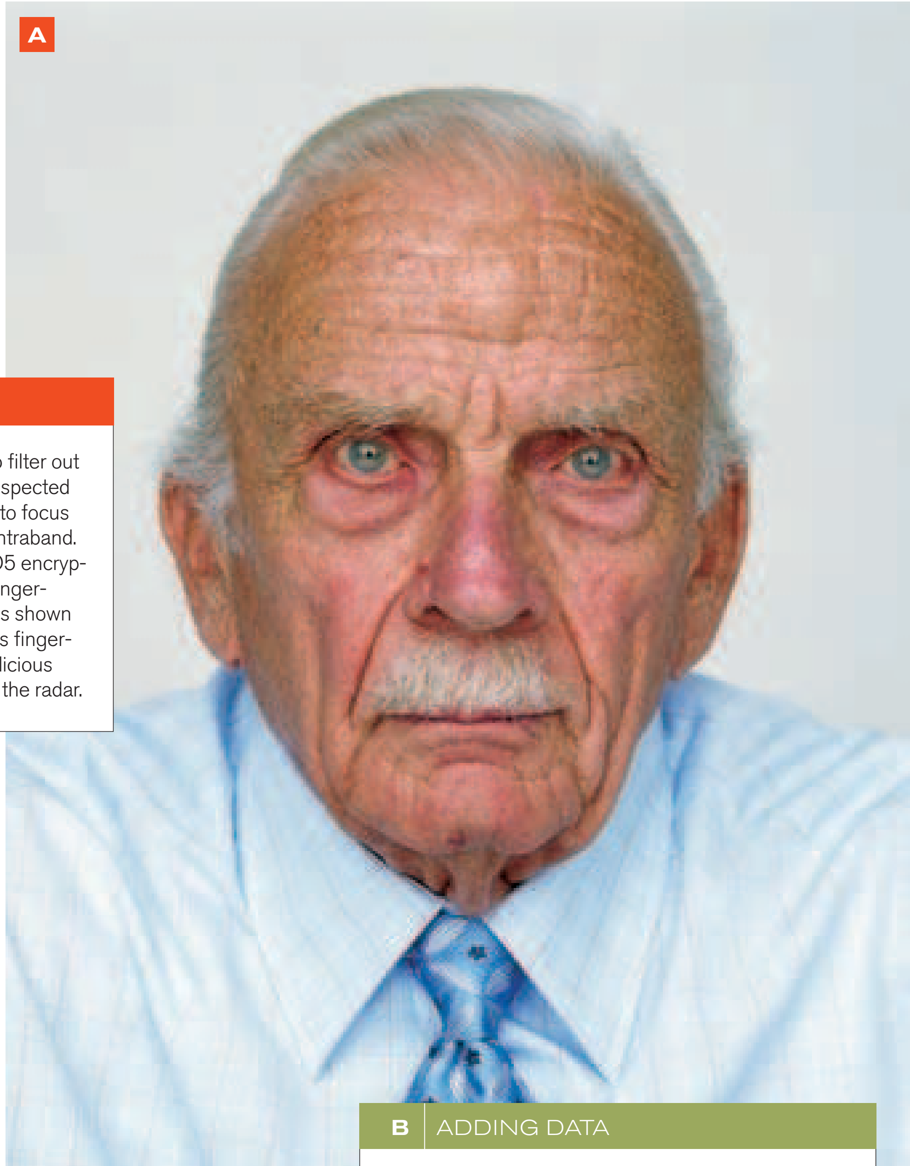
Turkle says that this kind of mechanical attachment instructs us in something important—maybe essential—about being human. Objects, she says, are locations where messy clouds of feelings can coalesce and take on form. My old computer, per this way of thinking, is less a machine for going online than it is a haunted relic, polished by the daily attentions of a supplicant and filled with a mystical energy that certainly doesn't come from its battery (which, by the way, is so shot that I must always keep the stupid thing plugged in, a real café liability). I can transfer my files, but I can't transfer my feelings to my new machine, at least not immediately. Instead, I plan to keep doing what I'm doing, though it makes no sense—using both laptops a little each day, hoping to eventually build up enough of an attachment to the new one to wean myself off its filthy, sluggish predecessor completely.

This elaborate, illogical way of coping with emotional and physical dependency on a machine makes sense to Turkle, who concludes *Objects* by envisioning a cyborg future when computers will stop just feeling like part of our bodies and start actually being them. "As we begin to live with objects that challenge the boundaries between the born and created and between humans and everything else, we will need to tell ourselves different stories," she writes. These books, inconsistent and dorky as they can be, are where that kind of storytelling starts. TR

EMILY GOULD BLOGS AT EMILYMAGAZINE.COM. HER FIRST BOOK OF ESSAYS WILL BE PUBLISHED BY FREE PRESS IN EARLY 2010.

SETH JOEL/GETTY IMAGES

HACK



A | TWO DOCUMENTS

Digital fingerprints are sometimes used to filter out known files among the thousands on a suspected criminal's computer, helping investigators to focus on files that might contain evidence or contraband. But Marc Stevens can use the broken MD5 encryption algorithm to give two files the same fingerprint—as, for example, with the two images shown here. If a harmless manipulated file gets its fingerprint listed in a commonly used library, malicious files sharing its fingerprint could fly under the radar.

Sharing Fingerprints

HACKERS CAN MANIPULATE OUTDATED ALGORITHMS TO GIVE TWO VERY DIFFERENT DOCUMENTS THE SAME DIGITAL SIGNATURE.

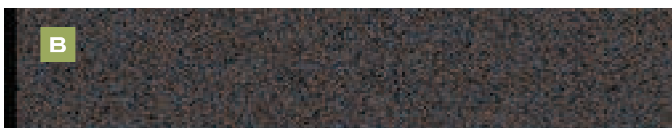
By ERICA NAONE

SENSITIVE ONLINE documents, such as certificates that vouch for banking sites, bear "digital fingerprints" that identify them without revealing their contents. The fingerprints are produced from the documents' contents by algorithms that are supposed to be irreversible. But recently, older varieties of the algorithms have been weakened. The venerable MD5, for example, has been broken, making it easy to introduce a forgery. Marc Stevens, a PhD student in cryptology at the Centrum Wiskunde and Informatica in Amsterdam, the Netherlands, has created a series of demonstrations of how MD5 can fail. One is shown here: though the two faces are different, their digital fingerprints are the same. This is a harmless example, but it has serious implications for digital forensics.

B | ADDING DATA

Stevens starts by adding junk data to each file to make them the same size. (MD5 checks a file's length.) He then figures out the difference between the two files' fingerprints. He continues to add data to both files, now calculated to reduce the differences between their fingerprints. This image, read from left to right, illustrates the approach: the colored bits represent the differences that result as Stevens's process is applied again and again, until it finally yields identical fingerprints.

WILLIE MALDONADO



C | DIGITAL FINGERPRINT

A digital fingerprint identifies a file without revealing its contents. Though it's theoretically possible for two files to have the same fingerprint, a good cryptographic hashing algorithm is supposed to make that nearly impossible. Stevens is able to use his system to manipulate any two files so that they produce the same MD5 fingerprint—a situation called a "collision." Digital fingerprints can be used to create digital signatures (pictured), which can certify a document's identity and origin.

C

0EAC4046 ED283A74 41A9BFFD 6C1289CC 5C58EB38
8F5C1379 4872BABA 2C1DC1FD 6CD247CC E9B76B18
2A278851 DA4C40C5 4F2F07A6 92AF5406 0DAA840E
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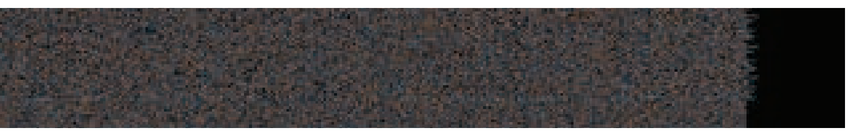
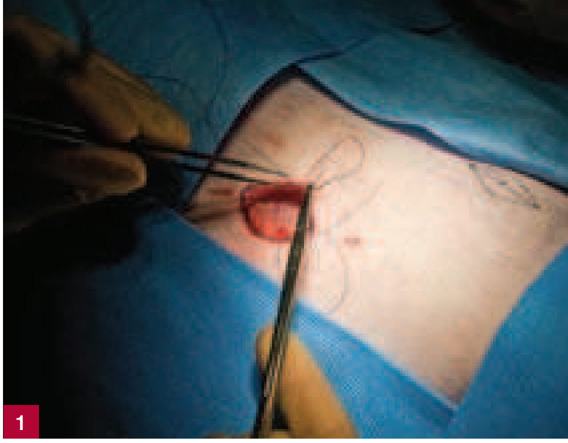
65459754

FAST PROCESSING

Though it's always technically possible to manipulate two files until they yield the same fingerprint, a strong algorithm can't be broken without vast amounts of time and processing power. But Stevens's system works with easily obtained resources. He forced the images shown here to produce a matching fingerprint in only one day, using his laptop and a PlayStation 3 console. Stevens says that the multiple computing cores of the PlayStation allow it to perform like a cluster of 40 PCs for the purpose of completing cryptographic calculations.



DEMO



Laser Show in the Surgical Suite

LASERS AND A CENTURY-OLD DYE COULD SUPPLANT NEEDLES AND THREAD.

By LAUREN GRAVITZ

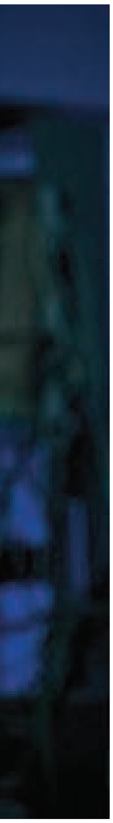
Despite medicine's inestimable progress over the past century, surgery can still leave scars that look more appropriate to Frankenstein's monster than to the beneficiary of a precise, modern operation. But in the Wellman Center for Photomedicine at Massachusetts General Hospital, Irene Kochevar and Robert Redmond have developed a method that has the potential to replace the surgeon's needle and thread. Using surgical lasers and a light-activated dye, the researchers are prompting tissue to heal itself.

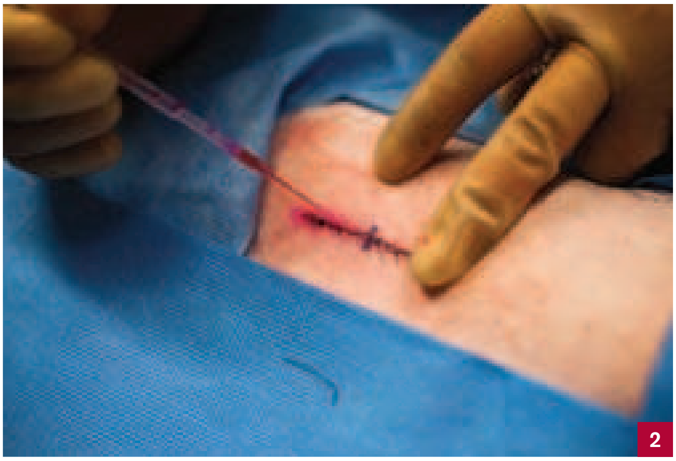
Laser-bonded healing is not a new idea. For years, scientists have been trying to find ways to use the heat generated by lasers to weld skin back together. But they've had a difficult time finding the right balance. Too little heat and a wound won't heal; too much and the tissue dies. Eight years ago, one of Kochevar and Redmond's colleagues was examining pathology slides of cells killed by this kind of thermal healing when it occurred to him that it might be possible to use just the light of a laser, rather than its heat.

While the idea of skin weaving itself back together may sound more like superhero lore than surgical skill, the science is startlingly simple. The team took advantage of the fact that a number of dyes are activated in the presence of light. In the case of Rose Bengal—a stain used in just about every ophthalmologist's office to detect corneal lesions—the researchers believe that light helps transfer electrons between the dye molecule and collagen, the major structural component of tissue. This produces highly reactive free radicals that cause the molecular chains of collagen to chemically bond to each other, or "cross-link." Paint two sides of a wound with Rose Bengal, illuminate it with intense light, and the sides will knit themselves back together. "We call this nano suturing," Kochevar says, "because what you're doing is linking together the little collagen fibers. It's way beyond anything that a thread of any kind can do."

The benefits of such nano suturing are manifold. In just about every case, it appears to result in faster procedures, less scarring, and possibly fewer infections, since it seals openings completely and leaves no gap through which bacteria can penetrate. This makes it particularly well suited for closing not only superficial skin incisions but also those made in eye and nerve operations. In eye surgeries, such as corneal replacement, stitches that can cause irritation and infection must sometimes be left in place for months, which can aggravate complications. In nerve surgeries, damage from scar tissue can decrease the conduction of neural

PORTER GIFFORD





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Left: Irene Kochevar codirects research into healing surgical incisions with laser light at Massachusetts General Hospital.
1. After removing a small ellipse of tissue from an anesthetized rabbit, surgeon Ying Wang sews the deeper layers of the wound shut with traditional sutures; the laser that the team uses does not penetrate this deep tissue and so cannot bind it together.
2. Wang has closed the right half of the epidermal wound with cosmetic stitches. She then drips Rose Bengal dye onto the left half.
3. Wang and surgeon Min Yao position a metal frame that directs a green surgical laser over the incision. The frame keeps the instrument steady and at a measured distance from the skin. They shine the light onto the cut to activate the dye, leaving it on for three minutes.

3

impulses. "If you put a needle through skin, it's not a big deal," says Redmond. "But if you put it through a nerve it's a big deal, because you're destroying part of the nerve."

LIGHT WORK

The operations take place in a surgical suite of tile and stainless steel. Min Yao, a surgeon on Kochevar and Redmond's team, has carted a medical laser up from the lab downstairs. The instrument is already used for eye, ear, nose, and throat procedures, and its green light has just the right wavelength for maximum absorption by the pink Rose Bengal stain. The better the light is absorbed, the more it activates the dye and the more complete the collagen cross-linking. The box that generates the laser light is barely larger than a stereo receiver; a thin fiber-optic cable snakes out of its side, and it gives off an appletini-green glow.

For this particular test surgery, on the skin of an anesthetized rabbit, surgeon Ying Wang measures and marks a patch of skin to be removed, an elliptical, leaf-shaped patch 1.5 centimeters wide by 3.5 centimeters long. After removing the tissue, Wang begins closing the wound. Surgical cuts typically require two layers of suturing:

buried, or subcutaneous, stitches to bring deep tissue together, and superficial ones to close up the skin itself. Wang moves her needle and thread through the subcutaneous layer, working her way deftly from one end of the incision to the other. Then she moves on to the epidermal layer.

Wang closes up the right half of the cut with three stitches, black thread standing out against the rabbit's pink skin. Then she takes a vial of Rose Bengal and drips the neon-pink dye onto either side of the unclosed portion of the wound. She threads the laser's fiber-optic cable into a metal stand, which maintains a set distance between laser and tissue while holding the light steady; a lens focuses the beam into a sharp, straight line that can be aligned with the incision. Wang positions the stand on the rabbit's flank, dons a pair of orange safety glasses, sets a timer, and steps down on the pedal that activates the laser. A green glow washes over the room.

Three minutes later, the timer beeps and Wang releases the pedal. She removes her safety glasses, moves the laser stand away, and inspects her handiwork. A small line is visible—a remnant of theRose Bengal stain and of the black marker used to trace the location of the incision prior to surgery. But when she tugs on the wound, using a pair of forceps in each hand to pull the skin apart, the skin holds taut, and there's little visible evidence of the cut itself.

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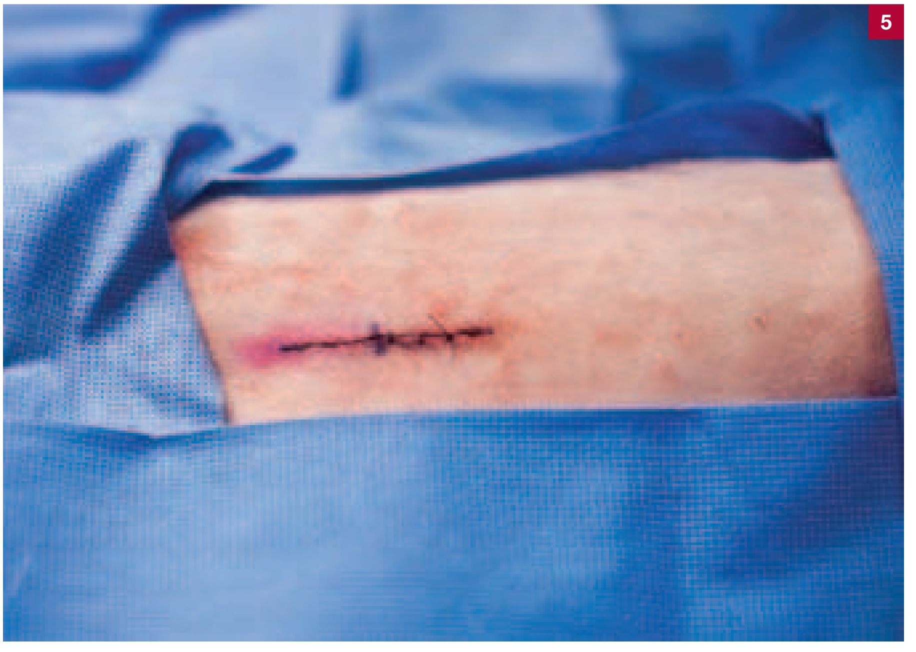

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4. A lens in the metal stand modifies the shape of the laser's focal point so that it's ideal for healing a long, thin surgical incision. Activated by the light, the Rose Bengal stain causes collagen fibers in the skin to link, sealing the wound. **5.** Once the laser is removed, the left half of the incision remains closed without sutures; it requires no further care and will leave behind almost no scar. The stitches on the right half, however, must remain in place for up to two weeks and will result in small but visible crosshatch scars.

A BRIGHT FUTURE

"It's a very interesting technology, which would be useful to anyone who does any kind of skin surgery—plastic surgeons, dermatologists," says Robert Stern, a professor of dermatology at Harvard Medical School and chief of dermatology at Beth Israel Deaconess Medical Center in Boston. He notes that the technology must still prove itself, and he isn't yet convinced that the benefits will offset the costs of photochemical dyes and laser equipment, which are far pricier than a needle and thread. But, he says, the potential to minimize scarring and perhaps speed healing "could be nice for patients and improve outcomes [too]."

So far, use of the technique in humans has been limited to skin surgeries: in a clinical trial, 31 patients with skin cancers and suspicious moles had their three-to-five-centimeter excisions closed with sutures on one side and photochemical tissue bonding on the other. The dermatological procedure will be submitted to the U.S. Food and Drug Administration for approval, which the researchers are awaiting before beginning additional human trials. Animal experiments have already shown the technique to be useful in nerve, eye, and blood vessel surgeries, among others—so useful, in fact, that Kochevar and Redmond have surgeons ready and waiting to start human trials the moment the hospital approves them.

WWW See how Irene Kochevar uses laser light to heal wounds: **technologyreview.com/demo**

"Talk to just about any physician about this, and they have an idea for how it could be used," Kochevar says. The technology is limited by tissue depth: it works only where light will penetrate, so it could never replace subcutaneous sutures or be effective on dark or opaque tissue like liver and bone. The scientists have licensed the technology to a brand-new startup, still in stealth mode, which plans to commercialize the technology once it receives FDA approval. The company has just begun seeking its first round of funding. TR

MATERIALS

Nanotube Super-capacitors

A METHOD FOR MAKING ELECTRODES DOUBLES ELECTRICAL STORAGE CAPACITY

SOURCE: "LAYER-BY-LAYER ASSEMBLY OF ALL CARBON NANOTUBE ULTRATHIN FILMS FOR ELECTROCHEMICAL APPLICATIONS"
Paula Hammond et al.
Journal of the American Chemical Society 131: 671–679

Results: MIT researchers have developed a new technique for making thin films of multiwalled carbon nanotubes. The materials have low electrical resistance and can store about 160 farads of electrical charge per gram—a capacitance more than twice that of other carbon nanotube films and an order of magnitude higher than that of conventional carbon materials.

Why it matters: Since the films can store large amounts of electrical charge and discharge it rapidly, they are promising materials for supercapacitors, long-lasting batterylike devices that charge up quickly. The way they're made gives the researchers a great deal of control over their thickness and porosity, and thus over their electrical properties. That means the materials could be useful in diverse applications, including microbatteries for medical implants and flexible electrodes for electronics.

Methods: The researchers treated carbon nanotubes with either positively or negatively charged surface molecules, then put them into separate water suspensions. They dipped a substrate, such as a silicon wafer, alternately in the positive and negative nanotube solutions; the difference in charge created electrostatic attraction, causing the nanotubes to cling to one another without the need for chemical binders. (Previous nanotube films, which required such binders, did not have electrical properties as impressive as those displayed by a pure mat of nanotubes.) The researchers have now made nanotube films of varying thicknesses, released them from their substrates, and tested their electrical properties.

Next steps: The researchers will modify the nanotubes so that the materials can store even more charge. They are also developing faster assembly methods based on spraying rather than dipping.

Tough Ceramics

MATERIALS WITH A SEASHELL-LIKE MICROSTRUCTURE RESIST FRACTURING

SOURCE: "TOUGH, BIO-INSPIRED HYBRID MATERIALS"
Robert Ritchie et al.
Science 322: 1516–1520

Results: A composite ceramic whose microscale structure mimics that of nacre, or abalone shell, is the toughest (that is, the most resistant to fracturing) ever made. Composed of microscale bricks of an aluminum oxide ceramic cushioned by a polymer filling, it has properties comparable to those of aluminum alloys and is twice as tough as the best structural ceramics.

Why it matters: Ceramics are lightweight and strong,

CARBON POWER
Twenty layers of carbon nanotubes are assembled on a polymer backing.

SEUNG WOO LEE/ *JOURNAL OF THE AMERICAN CHEMICAL SOCIETY*

but when pushed past their limits, they fail catastrophically—fracturing rather than bending, as materials such as steel would. That has limited their use as structural materials. The new materials, which exceed the toughness of nacre, could replace heavier structural materials in vehicles, improving fuel efficiency. They could also do double duty as insulation and structural support for buildings.

Methods: Researchers at the University of California, Berkeley, and the Lawrence Berkeley National Laboratory created the material with the help of directional freezing of ice, a technique that one of them, Antoni Tomsia, refined. The researchers mixed aluminum oxide with water and froze the mixture by drawing the heat out from one side, which caused the ice to form distinct shapes. The ice served as a template, producing multiple layers of long, thin crystals of aluminum oxide, with microscopic bridges of the ceramic between the layers. After removing the water, the researchers crushed the aluminum oxide into tiny bricklike structures. Then they added a polymer "mortar" (polymethyl methacrylate) that created a cushion between the brittle bricks. The composite material is 300 times tougher than either constituent alone.

Next steps: The structure of the ceramic very closely mimics that of nacre, but nacre's structural elements are on the order of nanometers, not micrometers. By making the bricks smaller and closer together, the Berkeley researchers hope to achieve a tougher material. They are also exploring ways to replace the polymer with other materials, in order to increase the ceramic's tolerance of high temperatures.

BIOMEDICINE

Cellular Fusion

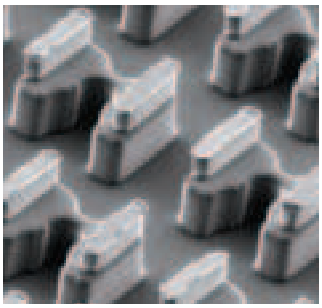
A MICROCHIP EFFICIENTLY PAIRS CELLS TO CREATE HYBRIDS

SOURCE: "MICROFLUIDIC CONTROL OF CELL PAIRING AND FUSION"
Joel Voldman, Rudolf Jaenisch, et al.
Nature Methods 6: 147–152

Results: A microfluidic chip designed by scientists at MIT efficiently traps different cell types and pairs them so that they can be fused into hybrids, a technique that is commonly used to study biological processes and can also be used to "reprogram" cells. The chip produced successfully fused hybrids five times more efficiently than commercially available devices do.

Why it matters: Fusing a stem cell to a differentiated adult cell can cause the adult cell to revert to an earlier developmental state; this reprogramming is one of the most exciting advances in stem-cell research, making it possible to generate stem cells from adult cells rather than embryonic ones. To better understand this phenomenon, researchers need a way to easily fuse large numbers of cells. The new technology will allow scientists to study the process in greater detail, perhaps enabling them to reprogram cells more efficiently.

Methods: The researchers built a two-square-millimeter chip dotted with tiny structures designed to trap cells. One side of each trap can hold no more than one cell, and the other side can hold two cells. When the researchers inject a solution containing cells into the chip, some of the cells are trapped on the one-cell side. A second squirt of fluid moves the captured cells to the side of the trap that holds two cells. Next, a solution containing a second cell type is injected into the device, and the two cell types are captured together. Finally, an electrical jolt delivered to the device fuses the two cells' membranes.



CELL TRAP These microscopic structures position pairs of cells so they can be fused together.

Next steps: The researchers plan to study how adding different proteins to the cell-containing solutions affects the efficiency of fusion and reprogramming.

Genetic Clock

ENGINEERED MAMMALIAN CELLS KEEP TIME

SOURCE: "A TUNABLE SYNTHETIC MAMMALIAN OSCILLATOR"
Martin Fussenegger et al.
Nature 457: 309–312

Results: Scientists at the Swiss Federal Institute of Technology Zürich genetically engineered a molecular oscillator that turned the production of a fluorescent protein in a hamster cell on and off every two to three hours for more than 20 hours. Changing the amount of DNA added to the cells varied the frequency of the oscillations.

Why it matters: Genetic oscillators could have numerous applications in genetic engineering and drug delivery. The clock might be adapted to deliver a protein drug; the frequency and amplitude of the oscillations would determine the dose of the drug and how often it was delivered. The findings may also help scientists understand the molecular clocks mediating numerous biological functions, such as circadian rhythm.

Methods: Researchers modified the hamster cells with DNA containing the code for a specific gene and the complement of that code. Turning on that gene creates an RNA transcript for a transcription factor, a protein that in turn activates production of a fluorescent protein and a second transcription factor. An excess of the second transcription factor activates the

ALISON SKELLEY

complementary code, which produces the mirror image of the original RNA transcript. This mirror transcript binds to the original RNA transcript, stopping the production of the fluorescent protein and the second transcription factor. Without the second transcription factor, the mirror transcript is no longer produced, and the concentration of the regular gene transcript begins to build again.

Next steps: The researchers are now trying to get the oscillator to function synchronously in an entire population of cells, which will be necessary if it is to be used for drug delivery.

INFORMATION TECHNOLOGY

Chip Chiller

ON-CHIP COOLING COULD INCREASE PERFORMANCE AND DECREASE POWER CONSUMPTION

SOURCE: "ON-CHIP COOLING BY SUPERLATTICE-BASED THIN-FILM THERMOELECTRICS"
Ravi Prasher et al.
Nature Nanotechnology online, January 25, 2009

Results: Researchers at Intel, Arizona State University, and Nextreme Thermal Solutions and RTI International, both located in North Carolina, have integrated a thermoelectric cooler into a computer chip for the first time. The semiconductor-based device, which uses electric current to move heat from one place to another, cooled a targeted region in a chip by 15 °C.

Why it matters: When microprocessors and opto-

BRRR A thermoelectric cooler, at the center, on a copper plate.

electronics operate, they generate heat; too much can inhibit performance and reduce reliability. Today's cooling systems use flat metal plates attached to a chip to disperse the heat, and metal heat sinks, fans, and liquid-based cooling systems to remove it. But these technologies are bulky and inefficient. If small thermoelectric coolers could be built onto the heat-dissipating metal plates to target hot spots in the chip, they could replace other cooling systems and save space. Such focused cooling might also consume less energy.

Methods: The researchers selected thermoelectric coolers made from nanostructured thin films whose cooling properties had been proved superior to those of bulk thermoelectric materials. To attach a cooler to a copper plate already incorporated into the chip packaging, they applied an insulating material to the copper and deposited metal lines to serve as electrical connections to the cooler. Then they filled the spaces between the lines with a polymer for mechanical stability and soldered the cooler to the lines.

Next steps: Thermal resistance in the contact point between the cooler and the copper plate keeps the integrated device from cooling as effectively as a stand-alone device would. To reduce this resistance, the researchers are exploring alternative connectors, such as special types of solder and carbon nanotubes. They also plan to use more thermoelectric coolers to cover all the hot spots on a chip.

Smart Networks

A SOCIOLOGICAL THEORY COULD HELP OVERLOADED ROUTERS DIRECT TRAFFIC

SOURCE: "NAVIGABILITY OF COMPLEX NETWORKS"
Marián Boguña et al.
Nature Physics 5: 74–80

Results: Researchers at the University of Barcelona and the University of California, San Diego, have developed a mathematical model demonstrating that Internet routers can effectively deliver data even without detailed information about all the routers in a network. Having limited information about neighboring routers is enough.

Why it matters: The current system for routing data between the networks of different Internet service providers (ISPs) isn't expected to continue working as the Internet grows. The routers that handle this traffic require lists of network addresses, called routing tables, which tell them where to forward packets of information. These tables must be regularly updated, a process that can take minutes for a single change. As the network grows, the number of updates increases to the point that the tables are almost never up to date, and parts of the network are not accessible because addresses are missing. These problems could be avoided with the new model, since it doesn't require up-to-date routing tables.

Methods: The researchers looked to sociology experiments from the 1960s in which a person was asked to forward a letter to a stranger by sending it through friends and acquaintances. It took only a few hops for the letter to reach its intended recipient because people used clues, such as a friend's profession, to guess who might help move the letter closer. Similarly, the researchers' model shows that by using only a little bit of information about the nearest neighboring routers, such as their location and the type of traffic they recently received (data that can be acquired quickly via the direct link between neighbors), routers can continue to deliver packets of information even if their routing tables are missing addresses.

Next steps: The researchers suspect that they could further improve the performance of their model by looking at the location and traffic history of routers a few hops away from a particular router. They also hope to test the protocol in a working network. TR

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A Dream in the Desert

AN ARCHITECT'S QUIXOTIC BUT ENDURING QUEST TO CHANGE THE WAY WE LIVE

By MATT MAHONEY

A SITE TO SEE The sun sets on Arcosanti in the late 1970s.

IVAN PINTAR

Atop a mesa in the high desert of central Arizona sit the dozen concrete structures of Arcosanti, the model city conceived by the Italian-born architect Paolo Soleri as an "urban laboratory" for experiments in sustainable living. Founded in 1970, this homespun precursor to Masdar, the much larger project now under construction in another desert halfway around the globe *(see "A Zero-Emissions City in the Desert," p. 56)*, was an early attempt to combine innovative architecture with the clean technologies then at hand to conserve energy and minimize waste. It was to be a demonstration of Soleri's vision for how society could lessen its destructive impact on the environment.

A *Technology Review* correspondent who had spent four months at Arcosanti described the ambition behind Soleri's project in a 1979 special report:

The key to making cities instruments of progress rather than models of decline is to integrate all of their systems, says architect/philosopher Paolo Soleri. On but 13 acres of an 860-acre tract, he proposes to build a 25-story prototype that will house about 5,000 people and all the needed support systems.

Soleri believes that cities are the environments for the cultural and spiritual evolution of humanity; but he insists that their architecture be firmly based on ecological principles. "Instead of picking up one problem at a time and trying to solve it, we are trying to find a whole solution," he explains.

Like Masdar, Arcosanti needed to use the desert's most powerful force—the sun—to its advantage. But Soleri and his colleagues couldn't draw on vast streams of oil money (Masdar has billions in seed money, while Arcosanti relied on volunteer workers and the proceeds from the sale of ceramic and bronze bells produced on site). It had to be frugal.

Arcosanti, the first "arcology" (Soleri's word), is now six buildings and several arches that grace a desert mesa 70 miles north of Phoenix. This will be shadowed by a second design, the Two Suns Arcology. ...

The plans for the Two Suns Arcology, completed about three years ago, show that it will take greater advantage of new developments in solar energy than the first, cathedral-like model. Two Suns will be "energized by the sun," grow its own food, recycle its waste for agricultural nutrients, and have its own, largely self-contained economic system. While Arcosanti would employ some sophisticated hardware, Soleri emphasizes that "the application of the technology will be very different." The hemispheric-shaped building will face south ... its roof and structural overhangs tilted like two "blades" which will act as huge, passive solar collectors during the winter months when the sun is low in the sky and as providers of shade during the summer months of high sun. ...

WWW Explore a panorama of Paolo Soleri's urban laboratory in the Arizona desert: **technologyreview.com/arcosanti**

Electrical energy will be provided by whatever solar-cell technology is available at the time of major construction. The specifics of Two Suns' transportation network have not been worked out; but as an outspoken critic of the "asphalt nightmare," Soleri has designed a miniaturized city that does not include cars, in which rapid vertical transportation will tie things closely together. ...

Though Soleri's holistic approach suggests intriguing possibilities, designing and building the main structure of the arcology awaits massive funding.

The funding has yet to materialize, and today the project remains unfinished, with only a few dozen full-time residents. Yet the site draws thousands of tourists and volunteers who invest their time, effort, and money in the project for weeks or months at a time. Soleri, who received the National Design Museum's Lifetime Achievement Award in 2006, is still an active presence at Arcosanti. But even in 1979, he was resigned to the fact that he would not live to see his dream fulfilled.

At age 60, Soleri has begun to acknowledge that his city-in-the-sky may not be completed in his lifetime. But his vision of a human environment that produces its own resources, rather than eating up someone else's, is in our future. It is Soleri's insistence that man must evolve cities that give new life to the land and to the people in them. TR

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